TREASURY DEPARTMENT
UNITED STATES PUBLIC HEALTH SERVICE

HYGIENIC LABORATORY—BULLETIN No. 104

FEBRUARY, 1916

INVESTIGATION OF THE POLLUTION AND SANITARY CONDITIONS OF THE POTOMAC WATERSHED

WITH SPECIAL REFERENCE TO

SELF PURIFICATION AND THE SANITARY CONDITION OF SHELLFISH IN THE LOWER POTOMAC RIVER

By

HUGH S. CUMMING

PLANKTON STUDIES

By W. C. PURDY

and

HYDROGRAPHIC STUDIES

By HOMER P. RITTER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916


MAP OF
POTOMAC RIVER WATERSHED
Scale of Miles
0 5 10 20 30
POTOMAC RIVER WATERSHED DIVIDE
PENNSYLVANIA
MARYLAND
WASHINGTON
BALTIMORE
HAGERSTOWN
CHAMBERSBURG
WINCHESTER
BERRYVILLE
HARPERS FERRY
CUMBERLAND
PETERSBURG
STAUNTON
CHESAPEAKE BAY
POTOMAC RIVER
PT. LOOKOUT
U.S. PUBLIC HEALTH SERVICE.
L.H. WILDER.

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United States Public Health Service.

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INTRODUCTION.[1]

In the exercise of its constitutional powers, the Congress of the United States has, during the century and a quarter of its existence, passed numerous laws regulating the use of the navigable waters of the country as highways of interstate commerce. There is, however, so far as is known, no Federal law dealing with the pollution of interstate streams. Those who have suffered injury in person or property in consequence of such pollution must, it seems, ground their right to redress on the general principles of the common law or on statutes of the States.

Many of our States have placed upon their statute books laws to control the pollution of streams. Such laws have not only not interfered with the development of communities or the growth of their industries, but have also served to protect the health and decrease the death rate of their citizens.

Nevertheless, there are certain sanitary problems which, because of their magnitude or character, are national in scope and their solution devolves upon the Federal Government. One of the most important of these problems is the investigation of the pollution of navigable waters. Recognizing this need, Congress passed an act, which was approved August 14, 1912, providing among other things that the Public Health Service shall study "the pollution, direct or indirect, of the navigable waters of the United States."

Request for investigation of Potomac.—Under this authority the Surgeon General, with the approval of the Secretary of the Treasury, immediately began to arrange for the investigation of certain types of interstate waters. In the meantime, however, a joint communication under date of October 8, 1912, from the governor of Maryland and the governor of Virginia, and a communication of October 14, 1912, from the president of the Board of Commissioners of the District of Columbia, invited attention to the importance of investigations to determine the extent of the pollution of the Potomac River, and requests were made that a comprehensive study of the subject be undertaken by the United States Public Health Service.

These requests followed the publication of somewhat widely read statements that the sewage from the city of Washington and other communities along the Potomac River polluted the waters of the lower river to such an extent that there was danger of contracting

[1] Manuscript submitted for publication Jan. 14, 1915.

water-borne diseases, such as typhoid fever, by eating raw oysters taken from the extensive and valuable oyster beds which extend from Lower Cedar Point, about 65 miles below the sewer outlets of Washington, to the mouth of the river, which is about 100 miles below the outlets.

The District of Columbia was interested both because many of the oysters from the lower river are distributed and consumed in Washington, and because suggestions had been made that an elaborate sewage-disposal plant, to cost several millions of dollars, be installed for the treatment of Washington sewage.

Further reasons for studying Potomac.—Besides the requests from the authorities of Maryland, Virginia, and the District of Columbia, there were other reasons for studying the river. In connection with the International Joint Commission, Surg. McLaughlin, of the Public Health Service, was studying the pollution of the Great Lakes; and it had been determined by the service to study the pollution of the Ohio River as a type of inland stream with diversified pollution and with a number of communities dependent upon its waters for drinking purposes; and it was also desirable to study a tidal stream and estuary such as the lower Potomac.

Scope of the investigation.—In undertaking the investigation it was planned to secure data which might be applied, first, to the general problems encountered in sanitary investigations of waterways, and, second, to the peculiar problems of this river, which require solution. Both the general and the specific problems require for their settlement accurate information concerning two factors—the pollution and the purification.

Concerning the pollution, it is necessary to know its origin, character, and quantity. These are determinable by sanitary surveys, combined with certain morbidity data and biological and chemical studies. The data thus obtained must be submitted to critical analysis to determine in just what ways, if any, the pollution constitutes a sanitary menace. For example, a certain industrial waste must not be dismissed as having no sanitary significance merely because it is not poisonous and does not contain disease germs; it must be considered whether this waste contributes to the exhaustion of purifying agencies which might otherwise have been applied to the dissipation of disease-bearing pollution. After having made certain hydrographic, biological, and chemical studies, one is in a position to estimate the potency of the natural purifying agents.

The sanitary status of the waterway may be very accurately estimated from a consideration of the balance between the pollution and the purification under varying conditions; and, moreover, if the conditions are found to require remedy, the data for practicable measures to relieve the situation are ready at hand.

The instructions issued on December 24, 1912, by the Surgeon General of the Public Health Service, with the approval of the Secretary of the Treasury, contained the following:

The investigations in question will be undertaken through the hygienic laboratory. They should comprise an intensive sanitary survey of the entire Potomac River watershed. The watershed below Washington will require a very intensive survey, involving water examinations both bacteriologically and chemically, the samples to be taken regularly at many sampling points along the river. While the preliminary survey and the examinations of samples of water will be first undertaken, other problems will ultimately have to be considered, such as the effects of dilution and the natural agencies of purification upon the polluted water in given distances of stream flow and the effect of the sewage pollution in reducing the dissolved oxygen in the water.

After necessary conferences by officers of the State Board of Health of Virginia and the Public Health Service, and with the advice of Prof. William T. Sedgwick, who occupies the chair of biology and public health in the Massachusetts Institute of Technology and is a member of the advisory board of the hygienic laboratory, it was decided to collect data which may be classified as follows:

A. *Data on the gross physical characters of the river and its catchment basin:*
- (*a*) The watershed—areas, rainfall, run-off.
- (*b*) The tributaries—daily discharge.
- (*c*) The river proper—topography, cross sections, gradients, stream flow, scour.
- (*d*) The estuary and its tidal basins—areas, volumes, tides, float data, scour, winds, volumes.

B. *Data on the pollution of the river:*
- (*a*) The water—
    1. Sanitary survey data—typhoid fever prevalence, amount and character of sewage, trade wastes, and surface wash.
    2. Physical and chemical data—suspended matter and turbidity, free ammonia, chlorine, salinity, oxygen, putrescibility, residue.
    3. Biological data—total bacterial count, *B. coli* count, plankton data, higher aquatic life.
- (*b*) The bottom mud—
    Physical, chemical, and biological data.
- (*c*) Shellfish industrially important—Oysters; extent of industry, total bacterial count, *B. coli* count.

C. *Data on the natural purification of the river:*
- (*a*) The water; (*b*) the bottom mud—Physical, chemical, and biologic data similar to or derived from the foregoing, especially amount of dilution, the time factor, sources of oxygen, plankton data, aquatic plant life, oxygen determinations, total bacterial count, *B. coli* count.

It transpired, as had been foreseen, that the methods employed were subjected to tests as to their value during the investigation, since, where several methods were employed for the solution of the

same general problem, they acted as checks upon each other. No method was servilely followed, it being desired to learn something as to the value of current practices at the same time that the river was investigated. More intimate details as to the scope of the investigation and of the methods employed are given in their appropriate sections throughout the report.

There have been, both in this country and abroad, many exhaustive studies of the pollution of rivers and shellfish beds and many studies of industrial wastes. A careful survey of available literature, however, has disclosed no reported investigation which has attempted a study of an entire river over a period of a year and embracing so many of the problems involved in the pollution of rivers.

Organization.—In the letter already quoted it was directed that the director of the hygienic laboratory, Surg. John F. Anderson, should "assume supervision over the investigations to be made by officers attached to the laboratory."

Surg. H. S. Cumming was designated to have immediate charge of the field work. He had the assistance of Asst. Surg. W. F. Draper, in immediate charge of a temporary laboratory established at Colonial Beach, Va.; Sanitary Engineer Harry P. Letton, who, with Surg. Cumming, made the sanitary survey of the watershed; and Sanitary Chemist W. F. Wells and Sanitary Bacteriologist Henry V. Stewart, who were from time to time engaged in both field and laboratory work. Biologist W. C. Purdy made the studies of the plankton and vegetable life of the river.

Following the appointment of Prof. Earle B. Phelps as chief of the division of chemistry of the hygienic laboratory, the investigators have had the advantage of his advice and assistance.

The great importance of certain hydrographic data concerning the estuary portion of the river resulted in the request being made of the Superintendent of the Coast and Geodetic Survey to furnish assistance. Accordingly Mr. Homer P. Ritter, who has had large experience in making such observations, was detached from the Mississippi River Commission and assigned to this work. He organized a field party, which began work in August, 1913.

Acknowledgments.—The officers in charge of the investigation desire to express their appreciation of the assistance given by the officers of the Coast and Geodetic Survey; by the Director of the Geological Survey in furnishing valuable figures as to run-off and daily discharge of the river and its tributaries above Great Falls; by the Commissioner of Fisheries and his staff in extending courtesies, including the loan of apparatus for securing deep-sea samples; by Prof. C. F. Marvin, Chief of the Weather Bureau, in furnishing data as to daily weather conditions in Washington; by Dr. W. T. Sedg-

wick, of the Institute of Technology, Boston; by the State health officers of Maryland and Virginia in furnishing maps and information as to the prevalence of typhoid fever; by the State commissioner of health of Pennsylvania in furnishing maps of certain districts of that State; by Dr. Francis E. Harrington, former health commissioner of Cumberland, Md., in permitting the use of the city laboratory; and by the officials of the Smithsonian Institution in the identification of certain mollusks.

Acknowledgments are due also to Mr. Asa E. Phillips, superintendent of sewers in the District of Columbia, who has cooperated most cordially and efficiently by furnishing the gasoline launch *Virginia* for the collection of samples, and who has supplied valuable data and daily samples of sewage for examination. As bacteriological examinations of water from the Great Falls intake are made daily at the laboratory of the Washington Filtration Plant, the records made available by the superintendent rendered the collection of samples at that point unnecessary.

SUMMARY OF PREVIOUS INVESTIGATIONS.

In 1886 Theobald Smith made studies of the Potomac River water, during which he found that the bacterial count was greatest in periods of high water, consequent upon rain and wash, rather than in periods of low water, when the amount of concentration of sewage would necessarily be greatest. (Med. News, 1887, vol. 50, p. 404.)

In 1897 and 1898, in accordance with a Senate resolution, Drs. Kinyoun and Sprague, of the Marine Hospital Service (now the Public Health Service), made a study of the pollution of the Washington water supply.

In 1898 the United States Geological Survey, in accordance with a Senate resolution, made a hydrographic survey of the Potomac River watershed above Washington. In connection with the work samples were collected from 55 points on the river above Washington and analyzed. The results of this investigation were published in Senate Documents Nos. 90 and 211, Fifty-fifth Congress, second session, and in the report of the Marine Hospital Service for 1898.

In 1905 Mr. Marshall O. Leighton reported the result of a study of the pollution of the river above Great Falls by sewage and industrial wastes, and considered it increasing and dangerous to the water supply of Washington. (U. S. Geol. Survey, 1900, S. Doc. No. 181, Mar. 1, 1905.)

In his presidential address before the Medical Society of the District of Columbia Mr. Thomas N. McLaughlin called attention to the importance of the pollution of the river to the city of Washington. (Wash. Med. Annals, January, 1906.) Illustrating some of the chief sources of pollution, he particularly mentioned as of growing importance the danger of infection from oysters fattened in fresh-water estuaries.

Lieut. Col. A. M. Miller, Corps of Engineers, United States Army, submitted a report upon the "Feasibility and propriety of filtering the water supply of Washington," which included a study of the relation of Potomac River water to typhoid fever. Chemical and bacteriological analyses of the river water are given in this report. In it Mr. Robert Spurr Weston also summarized much bacteriological and chemical data and gave the character and composition of the Potomac River water. (S. Doc. No. 259, 56th Cong., 1st sess.)

Messrs. Parker, Willis, Bolster, Ashe, and Marsh in 1907 made a study of the "geographical history, rain, and stream flow, pollution, typhoid fever, and character of the water; relation of soils and forest

cover to quality and quantity of surface water and effect of industrial wastes on fishes." The study was an exhaustive one, and included a sanitary survey of the basin down to Washington, but did not include any study of the bacterial life of the river, nor did it include the Potomac Basin below Washington. (U. S. Geol. Survey, Water Supply and Immigration Paper 192.)

The Public Health Service has for a number of years been studying the Potomac River water and its influence upon the incidence of typhoid fever in Washington. During the "Investigation of the prevalence and origin of typhoid fever in the District of Columbia" in 1906 and 1907, a sanitary survey of the upper watershed was made by Goldberger and studies of the bacterial life were made by Frost (Hygienic Laboratory bulls. 35, 44, 52, and 78). In Hygienic Laboratory Bulletin 78, Lumsden and Anderson discussed the relation of shellfish to the spread of typhoid fever in the District of Columbia. Anderson and Creel studied the bacteriology of oysters from the lower river and bay in 1910, but no report has been published.

Fairly constant bacteriological and turbidity records of the water at the city intake above Great Falls are made by the District authorities and are available in the annual reports of the Chief of Engineers, United States Army. The Corps of Engineers has made an exhaustive study of hydraulic data of the river with special reference to the generation of power at the falls. (Report on water supply, District of Columbia, H. Doc. No. 1400, 62d Cong., 3d sess., 1913.)

So far as known to us the only studies of the bacteriology and chemistry of the river below Washington have been those made by Dr. G. W. Stiles, of the Bureau of Chemistry, Department of Agriculture, upon one or two trips, and a joint investigation upon three trips made by representatives of the Bureau of Chemistry and the States of Maryland and Virginia. The results of these investigations have not been published.

The Bureau of Fisheries has made studies of the fish life in the river, but no plankton studies have heretofore been made.

It will thus be seen that, while many studies have been made on different portions of the river and upon isolated sanitary and economic problems presented by it, no coordinate effort has been made to collect and interpret sanitary data of the river as a whole so that the interplay of the various factors could be comprehensively understood. There have been two questions which, because they affected the largest groups of persons, have elicited all previous sanitary investigations of the Potomac River. The first of these is: Is the water of the upper Potomac so dangerously polluted as to be unsuitable, when untreated, as a water supply for the city of Washington?

This has repeatedly been answered in the affirmative, and as a consequence an elaborate sedimentation and filtration plant has been installed. The second question is: Is the water of the lower Potomac so dangerously polluted that edible shellfish cultivated therein are unsuitable for food? This has not perhaps been conclusively answered up to the present time.

The additional questions may be roughly summarized as follows: How, and to what extent, do rivers of which the Potomac is a type become polluted? What are the natural forces tending to dissipate this pollution and how do they operate? And, finally, What is the result from a sanitary viewpoint of the interaction of pollution and natural purification?

PHYSICAL AND ECONOMIC FEATURES OF THE POTOMAC RIVER.

It will be necessary at different places throughout this report to consider more intimately certain features which might well be grouped under the above heading. What follows is intended merely to afford a bird's-eye view of the river, so that the reader may be better oriented in perusing the subsequent sections. (See map No. 1.)

Because the Potomac presents two very distinct portions, with contrasted physical and sanitary features, it can conveniently be described as consisting of the upper and the lower river.

The upper river.—The upper river is comparatively narrow, fast flowing, though tortuous, flanked by steep banks or mountains, and is crossed here and there by dams and rapids. It receives many tributaries having on a smaller scale the same gross features as itself. It is formed about 25 miles below Cumberland, Md., by the junction of the north and the south branches of the Potomac and flows, with many crooks and turns, in a general southeasterly direction for a distance of 153 miles, to the Great Falls, where it tumbles over an irregular rocky shelf, forming the beginning of the lower river.

The tributaries of the upper river flow along the valleys between the mountain ridges of the Appalachian and Allegheny ranges, and hence those entering from the south flow in a northeasterly direction and those from the north flow in general southwesterly. The main stream cuts at right angles through the hills and mountains.

The watershed thus drained varies geologically from the granite sheds of the upper streams to the limestone regions of the Cumberland and Shenandoah. It contains areas of uninhabited virgin forest, highly cultivated agricultural land, and communities varying from isolated mountain hamlets to towns of considerable size and manufacturing importance. Beside the sewage of these communities, the river and its tributaries receive the surface wash of cultivated fields and the waste matter from many varied industries, important among which are mining, tanning, pulp milling, distilling, and dye manufacturing. The tributaries of the upper river arise in four States—i. e., Pennsylvania, Maryland, West Virginia, and Virginia.

The lower river.—In strong contrast with that portion of the stream just described, the lower river is broad, its relatively slow current does not flow constantly in one direction, but oscillates back and forth with the tide from Chesapeake Bay, and its windings are

less numerous, though on a greater scale. It receives few tributaries having the characters of flowing streams, but the broad shallows which border the deep main channel extend in many places over the adjacent flat lands, forming extensive tidal basins, rank with aquatic vegetation. Such flowing streams as do enter the river are often loaded with highly colored red clay in suspension.

Near the upper end of the lower river is the city of Washington, which discharges the untreated sewage of over 300,000 inhabitants into the river. Aside from this and the sewage from Alexandria the pollution is relatively unimportant, as there are few manufacturing establishments to contribute their wastes.

As the waters of the river approach the bay they become mixed with the salt water brought up by the tides, furnishing excellent conditions for the cultivation of oysters when the required degree of salinity has been reached. The oyster industry in the lower reaches of the river is large and important.

Politically the lower portion of the Potomac is unique. The National Capital is at its head and in its course it separates the States of Maryland and Virginia, which States have joint jurisdiction over the riparian rights of the stream. This portion of the river is essentially an estuary and will be frequently referred to as such.

No detailed description of the streams entering the Potomac nor of the communities of the watershed will be given at this place. The course of the former and the location of the latter can be found in the various maps and details will be given in the later sections, especially that on the sanitary survey. Table No. 8 summarizes the populations and areas of the watershed.

POLLUTION OF THE POTOMAC RIVER.

Regarded from a sanitary standpoint there can be no doubt that the pollution of streams which conveys the microbial cause of certain "water-borne" diseases is still the most important. This is because so many communities in this country continue to drink, bathe in, and eat shellfish cultivated in, waters thus polluted without adequate preliminary treatment. In the United States typhoid fever is the disease most frequently contracted in this manner, while certain types of dysentery and malignant diarrheas of children are strongly suspected of having at times a similar origin. There is always a possibility of chance contamination with the causative agents of Asiatic cholera and certain diseases which we commonly associate with the Tropics—a possibility which, although admittedly remote, must be ever borne in mind in view of our large European immigration and the return of our tropical workers.

It must be remembered, however, that many diseases which we do not class as "water-borne" have been shown to exhibit a remarkable diminution following improvements in the water supply—the Mills-Reinike phenomenon.

There are again other diseases, notably endemic goiter, which are still under a reasonable suspicion of association with certain, or rather uncertain, saline constituents of drinking water.

The pollution introduced by industrial wastes, even though it be not poisonous or otherwise pathogenic, is by no means a matter of indifference to sanitarians. It may constitute a distinct menace by exhausting the natural purifying agencies of the stream, which otherwise would be utilized in overcoming the pathogenic pollution; and, on the other hand, it may in certain fortuitous or intentional combinations actually act itself as a purifying agent, an example of this action being given in this report.

There is another manner in which gross pollution of streams act, although indirectly, as a distinct sanitary menace. An unsightly, ill-smelling stream encourages insanitary practices along its banks. Rubbish which may breed and attract flies and rats is deposited without compunction on the banks of such a stream, insanitary privies are built there, and the construction of the better and more sanitary type of buildings is distinctly discouraged. This contention is not far-fetched; its correctness can readily be verified.

In this survey it was realized that the question of pollution was much more important in certain portions of the river than in others, and the attempt was made so to distribute the activities as to obtain a maximum of essential information rather than to secure uniformity of observation in all possible directions, much of which would have little practical significance, at the sacrifice of much time, money, and effort. For this reason, direct observations of the kind and amount of pollution entering the river preponderate as regards the upper river, while bacteriological and chemical studies take precedence in the lower river.

In the following account of a sanitary survey of the Potomac watershed the data on typhoid fever are illustrative rather than complete. It was found that to ascertain the prevalence of the disease with exactness by survey methods would necessitate a house-to-house survey in many parts where the disease is very prevalent, but the population is scattered along narrow valleys and in mountainous regions. Such a survey would have required a large force of trained epidemiologists and a period of time not available for the present study. Furthermore, the compiled results would have had only historic interest, for happily the unfortunate sanitary conditions on the watershed are rapidly being improved. The illustrative observations are supplemented, however, by official reports from the State health organizations. Although in estimating the pollution of a stream the methods of field observations and laboratory study can not be divorced, it has been found convenient to consider them separately at first.

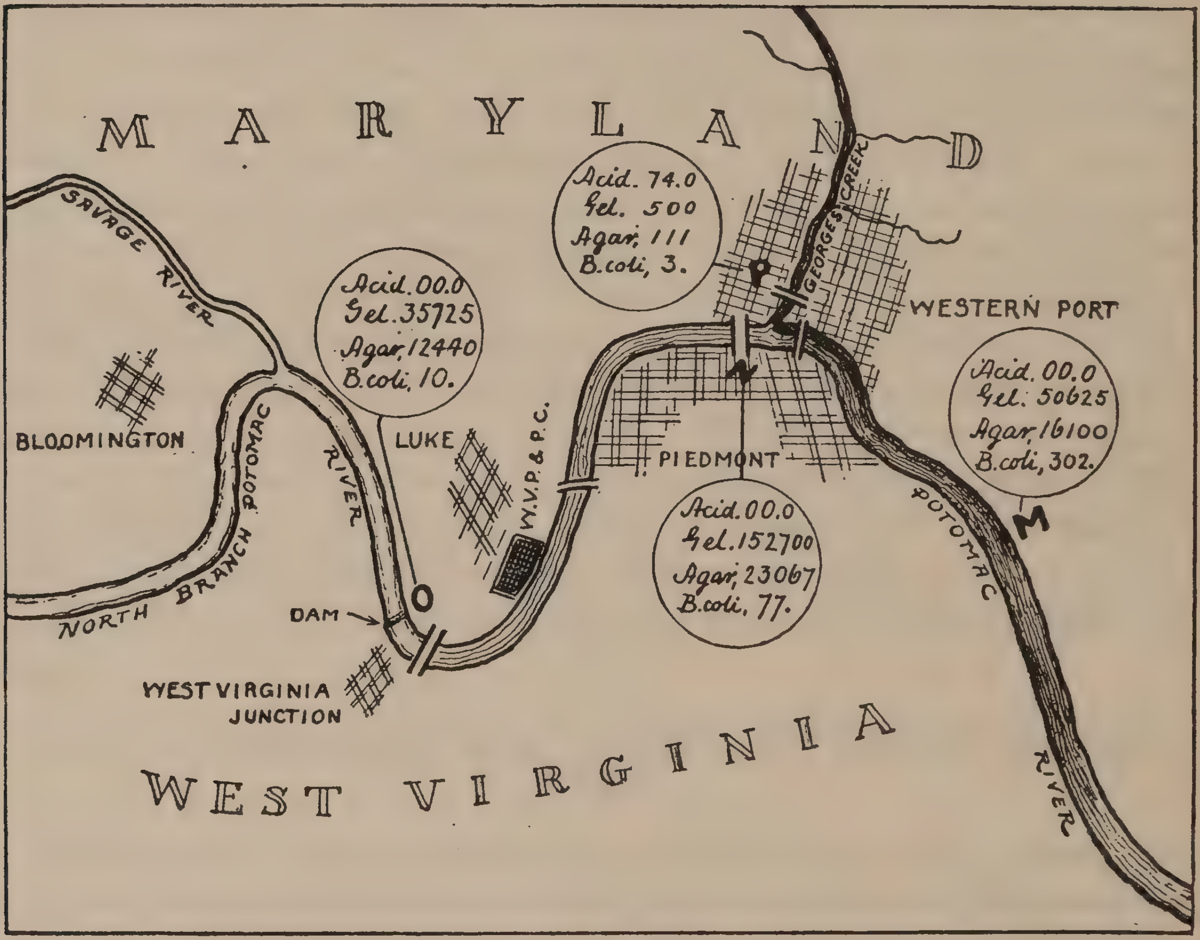
POLLUTION AS SHOWN BY A SANITARY SURVEY IN THE FIELD.

This sanitary survey attempted to determine to what extent the towns of the watershed are served by public water supplies and the source and amount of the supplies; the points at which pollution, either town sewage or trade wastes, enters or could enter the main stream or its tributaries, and the nature and extent of this pollution; and the prevalence of typhoid fever so far as ascertainable by practicable methods.

The general topography of the river has already been outlined. By reference to map 1 the location of the towns visited in the survey can be readily ascertained, since they are arranged systematically, beginning at the headwaters of the tributaries mentioned.

NORTH BRANCH OF THE POTOMAC RIVER.

This arises at the extreme southwestern corner of Maryland, near the West Virginia boundary, and flows in a northeasterly direction



MAP NO. 2.—VICINITY OF PIEDMONT, WESTERNPORT, LUKE, AND BLOOMINGTON, WITH SAMPLING POINTS AND THE RESULTS OF ANALYSES OF WATER THEREFROM.

for a distance of about 60 miles, to Cumberland, Md. Here it bends sharply to the southeast and some miles below it joins with the South Branch to form the Potomac proper. As a whole, the watershed is mountainous, but it is nevertheless fairly heavily populated, the larger portion of the inhabitants being engaged in mining and lumbering. Most of the communities are located directly on the streams. Gormania, W. Va., with a population of about 400, marks the first point at which direct pollution occurs. The town has wells and insanitary privies. At a tannery owned by the A. G. Hoffman Sons Co. about 150 hides are tanned daily. It was stated that all of the tan liquor was used repeatedly, and that none was discharged into the river. The lime wastes were discharged into a pit on the river bank, to be hauled away, it was said, at frequent intervals and used for fertilizer. The water in the river was somewhat discolored by tan liquor which had escaped. Dr. G. W. Drinkwater stated that "typhoid fever was common three years ago, but there have been only a few (six or seven) cases this year" (1913). Below this village the valley is narrow, and the small mining hamlets of Wallman, Gleason, Dobson, Shaw, and Harrison are strung out along the stream, with privies overhanging the river. Acid coal-mine wastes enter the stream from Gormania to Shaw. At Blaine, W. Va., and Kitzmillerville, Md., which together form a community (divided by the river, which is only 50 to 100 feet wide) of about 1,200 people, there is no public water supply or sewerage system. The stream is here polluted by several private sewers and overhanging privies and by the wash from several mines. Dr. Copeland, physician to the neighboring mines, stated that within a radius of 6 miles up and down the river from Blaine there were about 2,500 people, among whom there had been 15 cases of typhoid fever (one having been imported from Philadelphia) during the period January–October, 1913. Three years before there were over 300 cases of typhoid fever, of which 167 had been treated by himself.

Bloomington, Piedmont, Westernport (see map 2).—Bloomington, a community of 200 people, obtains a water supply to the extent of about 30,000 gallons a day from Piedmont, 2 miles below. It has no system of sewerage, but undoubtedly sewage finds its way into the streams. Dr. Kalbaugh, health officer of Westernport, stated that in 1911 and 1912 typhoid fever had occurred in nearly every family in Bloomington, and attributed cases in Piedmont to water thus contaminated. The Savage River, which enters the North Branch at Bloomington, drains a sparsely inhabited region, and at present affords an apparently excellent water supply for the town of Piedmont, and will shortly be utilized also for Westernport. About 2 miles below the mouth of the Savage River is the dam of the West Virginia Pulp & Paper Co., at Luke, Md., a town made up almost

entirely of the employees of this company. There is a public water supply obtained from the condensers at the paper mill. There is no sewerage system, but the sewage from the mill is discharged into the river. The mill wastes amount to about 23,000,000 gallons daily, and consist of lime, spent bleach, and clay used in sizing. These wastes markedly change the character and appearance of the river water. At times of very low water in the river the mill takes the entire flow and discharges a river of waste, and at the time of inspection, October, 1913, the river half a mile below the mill resembled a river of milk, due to the large amount of lime waste. Apparatus is being installed to save a large amount of this waste, and when this is in operation the appearance of the river will doubtless be improved. There was formerly (1910–11) so much typhoid fever in Luke that the operation of the mill was interfered with. Since the use of distilled water from the condensers the disease has practically disappeared.

Piedmont, W. Va., and Westernport, Md., are situated on opposite sides of the river about a mile below Luke. Piedmont, having a population of 2,054,[1] has a municipally owned water supply, derived from the Savage River about 5 miles above its mouth. At the time of the inspection this supply also furnished water in part to Westernport and Bloomington. Piedmont and Westernport together use about 510,000 gallons daily. Practically the entire town of Piedmont is sewered, the sewage discharging into the North Branch. The same is true of Westernport, which has a population of 2,702. Dr. Kalbaugh, of Piedmont, said that there had been 150 cases of typhoid fever, with a mortality of 10 per cent, as a yearly average for the past three years in the towns of Luke, Piedmont, and Westernport, which aggregate about 6,000 inhabitants. In his opinion this undue prevalence was caused by the occasional supplementing of the Savage River supply by pumping in water from the North Branch. The health officer of Westernport stated that 36 cases of typhoid, with 6 deaths, had been reported between May 13, 1913, and October 13, 1913. Two years previous to that time "the disease was prevalent and in severe form." During the year 1914 there was another outbreak. The results of bacteriological studies in this region are indicated in Map 2.

Georges Creek.—Georges Creek, which joins the North Branch at Westernport, has its source about 15 miles northwest therefrom, at Frostburg, Md. The watershed is very thickly settled, small towns being located in an almost continuous line throughout the length of the valley. Frostburg, a town of 6,028 inhabitants, has a public water supply derived from springs along the Savage River near its

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[1] Where actual population figures are given they are taken from the 1910 census.

source, about 4 miles west of the city. The daily consumption is 350,000 gallons. A public sewerage system serves about one-half of the town, the sewage being discharged into Georges Creek. Compulsory sewer connections are being made and the vicious system of disposing of sewage by discharging it into old mines and cesspools is being abandoned. There are important bituminous coal mines throughout the valley, especially at the upper end, discharging large amounts of acid iron wastes into the streams, which are consequently highly colored with iron oxide and devoid of living things. Dr. J. Marshall Price and Dr. Griffith, health officers of Frostburg, stated that very little typhoid fever had originated in the town since the installation of the present water supply. For several years, however, one section seemed thoroughly infected, although its water and milk supplies and sewage disposal were the same as for the rest of the city. Upon investigation by the State and city health officials a house was discovered in which, during several years, every member of the family had had typhoid fever. The locality was cleaned up, and 200 people received antityphoid inoculation. Since that time the only case occurring was in a young man who had refused typhoid vaccination. At Eckhart, an old mining town of 1,200 people, about 1 mile east of Frostburg, typhoid fever was formerly very prevalent, but it is now rare. A recently constructed tunnel drains the mines into Braddock's Run.

Midland, Md., about 4 miles below Frostburg, with a population of 1,173, has a public water supply derived from springs on Elk Lick Run. The water is impounded in an open reservoir of 2,000,000 gallons capacity. The average daily consumption is 85,000 gallons. There is no sewerage system, but sewage doubtless finds its way into the creek. Dr. Charles, the health officer, stated that before the installation of the present water supply typhoid and epidemic meningitis had occurred for 25 years. There has been no typhoid since two years ago, when there were two cases, and meningitis is now uncommon.

The town of Lonaconing, with 1,553 inhabitants, is situated about 4 miles farther downstream. The town has a public water supply derived from springs and two surface streams, Koontz Run and Jackson Run, tributary to Georges Creek. The total storage provided by these two supplies is 7,000,000 gallons, and the average daily consumption about 150,000 gallons. Practically the entire town within the corporate limits is sewered, the sewage being discharged through several outlets into Georges Creek. Dr. Bullock, the health officer of Lonaconing, stated that 10 cases of typhoid fever had been reported from January 1 to October, 1913.

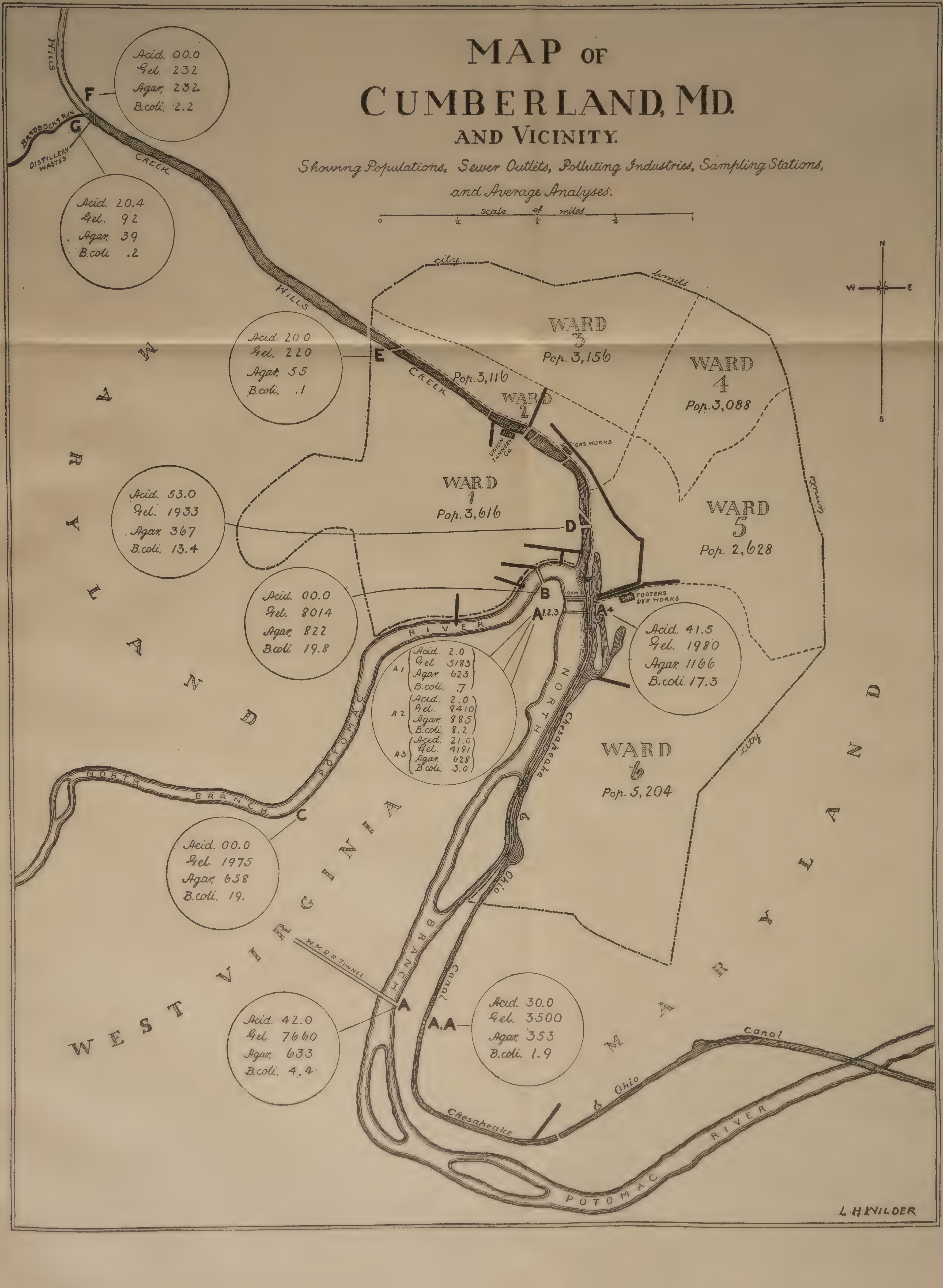
The mine waters probably exert a precipitating and germicidal action on the sewage of Georges Creek, since the waters of this

stream at their entry into the North Branch are of good quality as regards dangerous pollution. This acid iron water of Georges reacts chemically with the lime-laden water of the North Branch, causing the precipitation of iron hydrate, which carries down with it large amounts of organic matter. This action undoubtedly has an important effect upon the character of the water below this point.

Keyser.—Returning to the North Branch, the next place of importance is Keyser, W. Va., with a population of 3,705, situated about 5 miles below Piedmont. A municipally owned public water supply, derived from mountain springs 5 miles distant, furnishes water for the town. The storage reservoir at the springs has a capacity of 35,000,000 gallons. The town is sewered for the most part. This sewage and that from many private sewers is discharged into New Creek, which flows through the town, giving it a disagreeable appearance and odor. Piles of garbage and fecal matter line its banks. While the water of the North Branch immediately above Keyser is quite clear, it becomes very unsightly after receiving the sewage from private sewers and from the Baltimore & Ohio Railroad shops, and, like that of New Creek, harbors the gray fungus characteristic of sewage-polluted water. The Patchett Woolen Mills, located on the river bank, contribute large quantities of wool scourings and spent dyes, which at times markedly discolor the water for some distance below. Dr. W. H. Yeakley, the health officer, who has since died, stated that 15 cases of typhoid fever had been reported in Keyser from January to October, 1913, which was the smallest number in years.

From Keyser to Cumberland, a distance of about 18 miles, no direct pollution reaches the stream. At the latter point the pollution is so important, both qualitatively and quantitatively, that Sanitary Chemist W. F. Wells was detailed to make an intensive study of the situation. In order to preserve the geographical sequence his findings will be inserted at this point.

Cumberland.—Cumberland is situated in a natural basin which receives the drainage of a large area, in which extensive mining and paper-pulp industries contribute great quantities of their respective wastes to the pollution of the streams. With good transportation facilities, cheap coal, and natural gas, Cumberland and the surrounding towns are well located for industrial development and the support of a concentrated population. Within a radius of a few miles are industrial plants including a pulp mill, distillery, tannery, dye works, gas plant, and breweries. The wastes from these sources and the sewage which is discharged into the streams constitute a complex pollution which demands closer study. This study has been facilitated by the use of the city laboratory, which was generously permitted by the city authorities.


MAP OF CUMBERLAND, MD. AND VICINITY.
Showing Populations, Sewer Outlets, Polluting Industries, Sampling Stations, and Average Analyses.
scale of miles
0 ¼ ½ ¾ 1
N S W E
F
Acid. 00.0 Gel. 232 Agar. 232 B.coli. 2.2
G
Braddocks Run
Distillery Wastes
Acid. 20.4 Gel. 92 Agar. 39 B.coli. .2
Wills Creek
E
Acid. 20.0 Gel. 220 Agar. 55 B.coli. .1
city limits
WARD 3 Pop. 3,156
WARD 4 Pop. 3,088
WARD 2 Pop. 3,116
Union Tannery Co.
Gas Works
WARD 1 Pop. 3,616
WARD 5 Pop. 2,628
D
Acid. 53.0 Gel. 1933 Agar. 367 B.coli. 13.4
B
Acid. 00.0 Gel. 8014 Agar. 822 B.coli. 19.8
Dam
Footers Dye Works
A1,2,3
A4
Acid. 41.5 Gel. 1980 Agar. 1166 B.coli. 17.3
A1 Acid. 2.0 Gel. 5183 Agar. 623 B.coli. .7
A2 Acid. 2.0 Gel. 9410 Agar. 885 B.coli. 8.2
A3 Acid. 21.0 Gel. 4181 Agar. 628 B.coli. 3.0
WARD 6 Pop. 5,204
North Branch Potomac River
C
Acid. 00.0 Gel. 1975 Agar. 658 B.coli. 19.
Chesapeake & Ohio Canal
W.M.R.R. Tunnel
A
Acid. 42.0 Gel. 7660 Agar. 633 B.coli. 4.4
A.A
Acid. 30.0 Gel. 3500 Agar. 353 B.coli. 1.9
MARYLAND
WEST VIRGINIA
Potomac River
L.H. Wilder

The principal features of the problem are graphically indicated in map 3. It will be seen that the North Branch of the Potomac River makes a very sharp turn, forming an inverted V, at Cumberland, which is situated on its north bank. This is converted into an inverted Y by the entrance of Wills Creek from the north. The dam across the river just below this point is for the purpose of maintaining a sufficient head in the river to supply the Chesapeake & Ohio Canal, which begins here in a number of irregular basins. The flow from Wills Creek is directed to a large extent into the canal, and in times of low water it is said that the entire flow of the North Branch passes into the canal and none over the dam. The angle formed by the limbs of the Y is occupied by Knobly Mountain, through the base of which a railroad tunnel has been cut, which emerges at points some 2½ miles upstream and downstream, respectively, from the city. Wills Creek before it reaches the city contains strongly acid iron wastes. About three-quarters of a mile above the opening into the canal it receives a discharge of tan liquor, which precipitates black iron tannate, causing a discoloration of the water which can be traced down to the canal. The North Branch at the mouth of Wills Creek contains more or less alkaline calcium salts in solution, but since the canal is fed principally by water from the creek, it follows that the canal waters are acid and highly charged with iron compounds at the start. Either directly or indirectly, most of the sewage of the city reaches the canal. About one-half of the sewage from ward 1 goes into Wills Creek and half into the North Branch; approximately two-thirds of that from ward 2 flows into the creek, while the other third and all the sewage from wards 3, 4, 5, and 6 flow directly into the canal. The large canal basins, with their sluggish current, serve as settling basins for the sewage, which, moreover, receives chemical treatment by contact with the iron-laden water. This results in a heavy precipitation of the suspended matter. The iron sulphate acts not only as a precipitate and coagulant, but also as an oxygen carrier. The four atoms of oxygen in the molecule of sulphate are given up in the oxidation of organic matter, with a resulting precipitate of insoluble iron sulphide. The extent of this process can be judged from the fact that while the canal is in use one dredge is kept continually in operation removing the deposited sludge, which consists largely of iron sulphide. This is dumped into the river, where the excess of oxygen gradually reconverts it into sulphate.

Another reaction which takes place is that between the tannic-acid wastes from the Union Tanning Co. and the iron water, which results in a black discoloration and precipitate. On contact with the strongly reducing wastes from the James Clark Distilling Co. ferrous sulphate

is formed, producing a brilliant green discoloration. The ammoniacal waste from the gas works further tends to neutralize the acid water. Footer's Dye Works discharge some 40,000 gallons of wash water and spent dye into the canal daily. The interaction of all these chemical substances is naturally complex and variable, with quantitative fluctuations, but the final effect is to produce heavy precipitates, which carry down suspended organic matter with them and which can be removed by dredging.

Specimens were taken at various points, as shown in map 3, and examined bacteriologically and chemically in order to estimate the influence of the various pollutions and wastes on the sanitary condition of the water. These samples include some from the Piedmont region (see map 2) in order to show the condition of the water before the entrance of the wastes at Cumberland. During the time of taking specimens (April) there were frequent rains, which caused marked changes in the condition of the river and some irregularity in the findings. The results are given in tables 1 and 2, and the summaries are shown on map 3.

TABLE 1.—*The results of bacteriological examinations of water in the vicinity of Cumberland, Md., 1915.*

Place and date.	Sample No.	Bacteria per c. c.		B. coli in broth.				
		Agar.	Gelatin.	10 c. c.	1 c. c.	.1 c. c.	.01 c. c.	.001 c. c.
Canal bridge at tunnel below Cumberland:								
Apr. 13	AA	1,300	......	......	......	+	......	......
Apr. 17	AA	100	1,200	......	+	......	......	......
Apr. 23	AA	110	950	......	+	......	......	......
Apr. 27	AA	325	2,300	......	......	......	+	......
Apr. 28	AA	250	12,500	......	+	......	......	......
May 3	AA	35	550	......	+	......	......	......
Average per c. c.	......	353	3,500	1.9				
Potomac bridge at tunnel below Cumberland:								
Apr. 13	A	350	......	......	......	−	......	......
Apr. 17	A	325	1,600	......	......	+	......	......
Apr. 23	A	90	275	......	−	......	......	......
Apr. 27	A	650	17,500	......	−	......	......	......
Apr. 28	A	2,300	18,500	......	......	+	......	......
May 3	A	85	425	......	+	......	......	......
Average per c. c.	......	633	7,660	4.4				
Potomac bridge below canal dam at Cumberland, east pier:								
Apr. 15	A$_1$	950	3,900	......	......	−	......	......
Apr. 20	A$_1$	800	11,000	......	+	......	......	......
Apr. 24	A$_1$	120	650	......	−	......	......	......
Average per c. c.	......	623	5,183	.7				
Potomac bridge below canal dam at Cumberland, middle pier:								
Apr. 14	A$_2$	450	9,500	......	......	+	......	......
Apr. 15	A$_2$	2,500	13,500	......	......	......	......	......
Apr. 20	A$_2$	1,100	17,500	......	+	......	......	......
Apr. 22	A$_2$	75	750	......	......	+	......	......
Apr. 24	A$_2$	300	800	......	......	+	......	......
Average per c. c.	......	885	8,410	8.2				
Potomac bridge below canal dam at Cumberland, west pier:								
Apr. 14	A$_3$	350	1,600	......	......	−	......	......
Apr. 15	A$_3$	2,000	10,000	......	......	+	......	......
Apr. 20	A$_3$	75	4,800	......	−	......	......	......
Apr. 22	A$_3$	85	325	......	+	......	......	......
Average per c. c.	......	628	4,181	3.0				

TABLE 1.—*The results of bacteriological examinations of water in the vicinity of Cumberland, Md., 1915*—Continued.

Place and date.	Sample No.	Bacteria per c. c.		B. coli in broth.				
		Agar.	Gelatin.	10 c. c.	1 c. c.	.1 c. c.	.01 c. c.	.001 c. c.
Canal below canal dam at Cumberland:								
Apr. 9	A_4	3,100					+	
Apr. 15	A_4	1,300	5,000			−		
Apr. 14	A_4	1,000	3,000			−		
Apr. 20	A_4	150	1,100		−			
Apr. 22	A_4	130	325		+			
Apr. 24	A_4	150	475		+			
Average per c. c.		1,166	1,980	17.3				
Potomac bridge above Will's creek:								
Apr. 9	B	2,300						+
Apr. 13	B	550				−		
Apr. 15	B	950	4,500			−		
Apr. 14	B	1,000	8,500			−		
Apr. 17	B	90	550		+			
Apr. 20	B	550	22,500		+			
Apr. 22	B	200	950			+		
Apr. 23	B		3,500			+		
Apr. 24	B	200	800		+			
Apr. 27	B	230	950				+	
Apr. 28	B	2,700	17,500			+		
May 3	B	275	1,600		+			
Average per c. c.		822	8,014	9.5				
Potomac above Cumberland at tunnel:								
Apr. 13	C	250				−		
Apr. 15	C	1,600	5,500			+		
Apr. 17	C	170	750		+			
Apr. 23	C		100		+			
Apr. 27	C	475	1,800				+	
Apr. 28	C	1,100	1,800			+		
May 3	C	350	1,900			+		
Average per c. c.		658	1,975	19				
Wills Creek at Baltimore Street Bridge:								
Apr. 9	D	700					+	
Apr. 13	D	250				+		
Apr. 14	D	150	1,400			−		
Apr. 15	D	2,000	13,500			+		
Apr. 17	D	150	350					
Apr. 20	D	130	350		−			
Apr. 22	D	70	220		+			
Apr. 23	D		325		+			
Apr. 24	D	95	375			+		
Apr. 27	D	65	400		−			
Apr. 29	D	55	375		+			
Average per c. c.		367	1,933	13.4				
Wills Creek at B. & O. roundhouse:								
Apr. 9	E	130			−			
Apr. 17	E	75	80		−			
Apr. 22	E	13	550	+				
Apr. 27	E	39	140	−				
Apr. 29	E	18	110	+				
Average per c. c.		55	220	.04				
Wills Creek above Braddocks Run:								
Apr. 9	F	160		+				
Apr. 17	F	140	325	−				
Apr. 22	F	16	140	+				
Apr. 27	F	46	190		+			
Apr. 29	F	11	275			+		
Average per c. c.		75	232	2.2				
Braddocks Run above Wills Creek:								
Apr. 9	G	31			−			
Apr. 9	G	50			+			
Apr. 17	G	120	230		−			
Apr. 22	G	4	30	−				
Apr. 27	G	13	32	−				
Apr. 29	G	15	75	−				
Average per c. c.		39	92	.2				
Potomac, one-half mile below Piedmont:								
Apr. 11	M		2,000					+
Apr. 18	M	800	1,500			+		
Apr. 28	M	15,000	19,000				+	
May 3	M	332,500	180,000				+	
Average per c. c.		16,100	50,625	302				
Potomac bridge above Georges Creek:								
Apr. 11	N		9,000				+	
Apr. 18	N	1,200	1,800			+		
Apr. 28	N	31,000	200,000				+	
May 3	N	37,000	400,000				+	
Average per c. c.		23,067	152,700	77				

TABLE 1.—*The results of bacteriological examinations of water in the vicinity of Cumberland, Md., 1915.*

Place and date.	Sample No.	Bacteria per c. c.		B. coli in broth.				
		Agar.	Gelatin.	10 c. c.	1 c. c.	.1 c. c.	.01 c. c.	.001 c. c.
Potomac above dam at pulp mill, Luke:								
Apr. 11	O		1,500			+		
Apr. 18	O	200	600			+		
Apr. 28	O	120	800			+		
May 3	O	37,000	140,000			+		
Average per c. c.		12,440	35,725	10				
Georges Creek Bridge above Potomac:								
Apr. 11	P	210				+		
Apr. 18	P	120	1,100		+			
Apr. 28	P	65	450		—			
May 3	P	48	450		—			
Average per c. c.		111	500	30				
Canal at sewer near Footer's Dye Works:								
Apr. 14	aa	500,000						+
Wills Creek below tannery effluent:								
Apr. 9	bb	1,300						+
Wills Creek at North Lee Street Bridge:								
Apr. 9	cc	120			—			
Tan liquor from vat:								
Apr. 9	dd	11	300		—			
Mud from bed of canal:								
Apr. 22	xy	260,000	850,000					—
Apr. 27	xw	70,000	65,000				—	.0001
Cumberland city water, raw (Lake Gordon):								
Apr. 23	ee	475		—				
Settled water, Cumberland filter plant:								
Apr. 23	ff	39		—				
Cumberland filtered water at filter:								
Apr. 23	gg	15		—				
Cumberland tap water at laboratory:								
Apr. 23	hh	28		—				
Distillery wastes:								
Apr. 9	ii	37,500			—			
Apr. 9	ii	5,000			—			
Apr. 22	ii	27,500	45,000		—			
Apr. 27	ii	250,000	200,000		+			
Apr. 29	ii	10,000	9,000			+		
Feb. 17	ii	10,000	30,000		—			
Average per c. c.		56,667	94,667					
Potomac below discharge of pulp mill:								
Apr. 28	kk	35,000					+	
Lake Gordon (Cumberland water supply):								
May 7	LL	1,600		—				

TABLE 2.—*Showing results of chemical analyses of water from the vicinity of Cumberland, Md.*

Station number.	Location.	Date.	Acidity.	Alkalinity.	Iron.	Oxygen dissolved—		
						Before incubation.	After incubation.	Difference.
		1914						
A	Potomac bridge at tunnel below Cumberland	Apr. 13	78.0					
		Apr. 17			3.0	11.80	10.60	1.20
		Apr. 23		10.0				
		Apr. 27	6.0					
		Apr. 28			1.25			
	Average		42.0	10.0	2.13			1.20
AA	Canal, bridge at tunnel below Cumberland	Apr. 13	59.0					
		Apr. 17			1.5	10.80	9.80	1.00
		Apr. 23		4.0				
		Apr. 27	1.0					
		Apr. 28			1.5			
	Average		30.0	4.0	1.5			1.00

TABLE 2.—*Showing results of chemical analyses of water from the vicinity of Cumberland, Md.*—Continued.

Station number.	Location.	Date.	Acidity.	Alkalinity.	Iron.	Oxygen dissolved— Before incubation.	After incubation.	Difference.
		1914						
A_1	Potomac bridge below canal dam at Cumberland west pier	Apr. 15	2.0					
		Apr. 20		29.0				
	Average		2.0	29.0				
A_2	Potomac bridge below canal dam at Cumberland middle pier	Apr. 14	0.00					
		Apr. 15	4.00					
		Apr. 20		45.0				
		Apr. 22		21.5				
		Apr. 24		22.0				
	Average		2.00	41.70				
A_3	Potomac bridge below canal dam at Cumberland east pier	Apr. 14	42.0					
		Apr. 15	0.00					
		Apr. 20		14.0				
		Apr. 22		8.0				
		Apr. 24	21.0	8.0				
	Average		21.00					
A_4	Canal, Potomac bridge below canal dam at Cumberland	Apr. 14	75.0					
		Apr. 15	8.0					
		Apr. 20		9.0				
		Apr. 22		9.0				
		Apr. 24		7.0				
	Average		41.50	12.5				
B	Potomac bridge above Wills Creek	Apr. 13	0.00					
		Apr. 14	0.00					
		Apr. 15	0.00					
		Apr. 17	0.00					
		Apr, 20		22.0	1.0	11.0	10.0	1.00
		Apr. 22		22.0				
		Apr. 23		24.0				
		Apr. 27		21.0				
		Apr. 28		21.0	.5			
	Average		0.00	22.0	.75			1.00
C	Potomac above Cumberland at tunnel	Apr. 13	0.00					
		Apr. 15	0.00					
		Apr. 17			1.3	10.70	10.20	.50
		Apr. 23		18.0				
		Apr. 24		25.0				
		Apr. 27		24.0				
		Apr. 28			.35			
	Average		0.00	22.3	.83			.50
M	Potomac, one-half mile below Piedmont	Apr. 11	0.00					
		Apr. 18	0.00		1.0	10.0	8.60	1.40
		Apr. 28	0.00		2.0	9.20	8.80	.40
	Average		0.00		1.5			.90
N	Potomac bridge above Georges Creek	Apr. 11	0.00					
		Apr. 18			1.2	9.40	8.80	.60
		Apr. 28			.8	9.90	7.10	2.80
	Average		0.00		1.0			1.70
O	Potomac at dam above pulp mill at Luke	Apr. 11	0.00					
		Apr. 18			1.0	10.00	9.40	.60
		Apr. 28				9.40	9.40	.00
	Average		0.00		1.0			.30
P	Georges Creek bridge above Potomac	Apr. 11	74.00					
		Apr. 18			5.0	9.40	9.40	0.00
		Apr. 28			15.0	8.60	8.40	.20
	Average		74.00		10.0			.10
D	Wills Creek at Baltimore Street Bridge	Apr. 13	79.00					
		Apr. 14	98.00					
		Apr. 15	28.00					
		Apr. 17			3.4	11.00	10.60	.40
		Apr. 20		9.5				
		Apr. 22		7.0				
		Apr. 23		4.0				
		Apr. 24		5.0				
		Apr. 27	8.0					
	Average		53.2	16.37	3.4			.40

TABLE 2.—*Showing results of chemical analyses of water from the vicinity of Cumberland, Md.*—Continued.

Station number.	Location.	Date.	Acidity.	Alkalinity.	Iron.	Oxygen dissolved. Before incubation.	Oxygen dissolved. After incubation.	Oxygen dissolved. Difference.
		1914						
E	Wills Creek at Baltimore & Ohio roundhouse	Apr. 17			4.6	10.40	10.00	.40
		Apr. 22		3.0				
		Apr. 27	20.0					
	Average		20.0	3.00	4.6			.40
F	Wills Creek above Braddocks Run	Apr. 17			1.5	11.60	11.20	.40
		Apr. 22		2.00				
		Apr. 27		12.00				
	Average			7.00	1.5			.40
G	Braddocks Run above Wills Creek	Apr. 17			21.6	9.80	9.50	.30
		Apr. 22		2.00				
		Apr. 27	20.4					
	Average		20.4	2.00	21.6			.30

It appears from a consideration of these results that the sanitary condition of these waters is not nearly as bad as would be expected from mere inspection of the stream. The colon pollution is not excessive above the city where the water of Wills Creek has the most disgusting appearance, and the excess of *B. coli* noted immediately below the entrance of the sewers disappears a short distance down the canal and river. This reduction, moreover, is accomplished without exhausting the oxygenizing power of the river, which is restored by chemical reactions of the various commercial wastes. Here is an example of fairly efficient sewage disposal accomplished by a chance combination of wastes which so interact as to form purifying precipitates and oxygen-bearing compounds.

Cumberland now enjoys a new and improved water supply. It was installed in 1913, and it is believed that the typhoid incidence will be markedly reduced. The records of the Maryland State Board of Health show the following numbers of cases of typhoid reported in Cumberland during previous years: 1907, 121; 1908, 66; 1909, 118; 1910, 560; 1911, 320; 1912, 196; 1913, 160; June 1, 1913, to June 1, 1914, 299. Since the population of the town is about 22,000, it is evident that this constitutes an excessive prevalence of typhoid fever.

Area drained by Wills Creek.—Continuing the description of the watershed we will return briefly to the area drained by Wills Creek, the lower portion of which has been described. This stream rises about 25 miles north of Cumberland and receives its first pollution at the town of Hyndman, Pa., which has 1,164 inhabitants. A municipally owned water supply furnishes this town with about 40,000 gallons daily. The sewerage system, serving about 300 people, discharges into a small tributary of Wills Creek, and the latter at the time of inspection was in an offensive septic condition. Dr.

Rees, the health officer, stated that there was an average of 8 or 10 cases of typhoid fever annually.

About 10 miles below Hyndman, near Corrigansville, Md., Jennings Run joins Wills Creek. This small stream receives the indirect drainage of the small village of Mount Savage, in addition to a considerable amount of mine drainage. Further mine drainage is received from Braddocks Run, 2 miles lower down, which contributes wastes from the Eckhart mines, Clarysville, and Allegheny Grove. At the latter place the James Clark Distilling Co., operating during six winter months, discharges about 150,000 gallons of fermented and spent mash daily. This is carried through pipe to Wills Creek near Braddocks Run. The sewage of about 100 people is discharged directly into the latter stream. The heavy pollution of the lower part of Wills Creek and the chemical changes which take place therein have already been described.

Below Cumberland the North Branch receives but two important tributaries—Evitts Creek and Pattersons Creek—neither of which introduces significant pollution; in fact, the dilution afforded, especially by Pattersons Creek, is decidedly beneficial.

SOUTH BRANCH OF THE POTOMAC RIVER.

This stream, which is the second of the two main branches of the Potomac, rises in Highland County, Va., and flows in a northeasterly direction for about 100 miles to join the North Branch. Its principal tributaries are the North Fork and the Moorefield River. The drainage area of 1,490 square miles supports a population of only 27,000 people—the sparsest peopled area of the entire Potomac watershed. The inhabitants are for the most part engaged in lumbering and agriculture.

Franklin.—The first point at which the river receives pollution is Franklin, W. Va., about 25 miles below the source. Franklin is a village with a population of about 500, although only 200 of these reside within the corporate limits. A municipally owned public water supply is derived from the river near the upper end of the town and is pumped to an open reservoir. About 20,000 gallons are used daily. A separate public water supply for drinking purposes has been in operation for over 100 years. Until very recently this water was distributed through pipes made by boring holes through logs. The supply system was controlled by a self-perpetuating board of directors. This supply is obtained from a covered spring near the center of the town and is piped by gravity through the streets, the water being obtained from hydrants placed at frequent intervals. The town is partially sewered by a public sewerage system, the

sewage discharging into the river just below the point where the water supply is taken out. There are about 20 connections to the sewer. The only industry in Franklin is an old-fashioned cold-water tannery, with practically no liquid wastes. The Union Tanning Co. has purchased a site and a large amount of bark, with the intention of establishing a large tannery at this point. When this is in operation the river will undoubtedly receive a considerable amount of pollution. The six or eight cases of typhoid fever which occur annually seem to receive their infection from some constant source near the hotel.

From Franklin to Petersburg, W. Va., there is no direct pollution, with the exception of that from the small village of Upper Tract, the country being given over to farming and lumbering. Within a radius of seven miles of Upper Tract there live about 500 people, among whom, during the year 1913, there were 24 cases of typhoid, with 2 deaths, in the practice of Dr. Moore. The disease is almost wholly rural, as comparatively few cases seem to have occurred in towns and villages.

Petersburg.—Petersburg, W. Va., 30 miles below Franklin, is a town of about 500 population, without public water supply or sewerage system. It is the terminus of the Hampshire Southern Railroad, which runs between Romney, W. Va., and this point. The only industry of any importance is the tannery of the Union Tanning Co. This plant has a capacity of 110 hides per day, and tans only large hides for sole leather. The liquid wastes from the tannery, amounting to about 10,000 gallons per diem, are discharged into Lunice Creek. A settling pool has been constructed, through which all the wastes are supposed to pass, but at the time of inspection they were being discharged directly into the creek, which they discolored.

Moorefield.—About 11 miles below Petersburg, near the confluence of the South Branch and the Moorefield River, is situated the town of Moorefield, W. Va., with a population of 646. The town has a public water supply derived for the most part from the Moorefield River, although some water is obtained from a spring on a nearby mountain. The average daily consumption is about 15,000 gallons. The town is partly sewered, the sewage discharging into the river just below the town. There are about 20 connections to the sewer. About the same number of persons discharge sewage into a small open run which flows just back of the main street. The only industry of importance is the tannery of the Union Tanning Co., which is located about 2 miles southeast of the town on the Moorefield River. The tannery has a capacity of 90 hides per diem, and discharges about 10,000 gallons of liquid waste daily. This discharge is passed through two settling pools, which are emptied into the river during times of high water. The town water supply is pumped by the tannery, and

is taken from the river just above the point where the wastes are discharged. The settling basins at the time of the inspection gave off a very offensive odor.

Romney.—About 22 miles below Moorefield is the next town of importance, Romney, W. Va., with a population of 1,112. There is a municipally owned public water supply derived from springs near Mill Creek, about 4 miles southwest from the town. Part of the town is sewered, the system being owned by a private corporation known as the Romney Sewer Co. The sewer is discharged over a high bluff into the river just below the town. There are 44 connections to the sewer, which serves about 250–350 people. The West Virginia School for the Deaf and Blind is located in Romney, and at the time of the inspection was obtaining its water supply from the town. A well was being dug, however, from which it was planned to obtain the supply. About 20,000 gallons of water are used daily by the school. The sewage from the school building is discharged by two pipe lines into Shanks Run, a small Creek, one line being about 600 feet and the other about 300 feet long. The discharge from the latter line flows a few hundred feet over the ground to the creek. At the end of the pipe there was an accumulation of feces, paper, and other waste matter. This is a condition which should not be allowed to exist, as a small sewage-disposal plant could be constructed here at slight expense.

Dr. Shull, the health officer, stated that typhoid fever was not common in Romney, there being but six or eight cases annually and but two in 1913, one of which was imported.

Area from Romney to mouth of South Branch.—From Romney to the mouth of the South Branch there is no more direct pollution.

Near the junction of the North and South Branches is a scattered group of 50 or 60 houses, called "Green Springs." Dr. Wynkoop stated that there was an average of at least five cases of typhoid fever per annum among the 250 inhabitants. The town uses surface wells and open privies.

POTOMAC RIVER BELOW THE JUNCTION OF THE NORTH AND SOUTH BRANCHES.

The sanitary conditions in the basin below the junction of these two branches are in general better than in the mountain sections already described. The country is more thickly settled and the local health officers can learn of and remedy insanitary conditions more readily, and the towns are better provided with water and sewerage systems.

Town Creek, Little Cacapon Creek, Paw Paw.—About 3 miles below the mouth of the South Branch Town Creek enters the Potomac

River. This stream, which has a watershed of 150 square miles, rises in Pennsylvania and flows south. The population of the watershed is wholly rural in character. Three miles below the mouth of Town Creek Little Cacapon Creek enters the Potomac from the south. This stream has a watershed of 114 square miles, which supports a rural population of 157 persons per square mile. A few miles below the mouth of the Little Cacapon is the small town of Paw Paw, W. Va., where is located a tannery of the Union Tanning Co. About 45,000 large hides are tanned per year, although this is only about one-half of the capacity of the plant. The waste liquid, consisting of limewater, spent tan liquor, soak water, and wash water to the amount of about 50,000 gallons a day, is run into a pond having an area of about 3 acres. It was stated that the liquid would soak away and evaporate as fast as it was turned into the yard. At the time of inspection, however, there was a break in the dike and the waste was flowing directly into the river. There was considerable flow in the river at this time, but no discoloration was noticeable a few hundred feet downstream. It is alleged by residents in towns below the tannery that fishing has been ruined by the action of the wastes in the water.

Sideling Creek, Great Cacapon River.—Below Paw Paw the river follows a very tortuous course for about 26 miles, to a point where Sideling Creek enters from the north. There is no direct pollution in this latter stream, the watershed of which embraces an area of 95 square miles and supports a population of 38 per square mile. About 4 miles below the mouth of this stream the Great Cacapon River enters from the south. This tributary rises in the divide between Virginia and West Virginia and flows in a northeasterly direction along the west side of Great North Mountain, a distance of about 75 miles, to the Potomac. Its watershed has an area of 609 square miles. The country is mountainous and heavily timbered and supports an almost wholly rural population of 16.5 to the square mile. There is no direct pollution of the stream, the few communities being small.

Hancock, Berkeley Springs.—The town of Hancock, Md., is situated about 8 miles below the mouth of the Great Cacapon. This town has neither public water supply nor sewerage system, but has obtained permission from the State legislature to vote upon the proposition of issuing bonds for the construction of both. There is a private sewer discharging into the river, which serves two hotels, the Western Maryland station, and one or two other buildings. Opposite Hancock is the mouth of Warm Spring Run, a small tributary which receives the drainage of Berkeley Springs, a West Virginia community with a population of 864. This is a summer-resort town, and is the seat of a considerable industry in glass sand. The attrac-

tion of the town is the thermal springs, which issue at a constant temperature of 74° F. The town has a public water supply derived from Warm Springs, the average daily consumption being about 72,000 gallons. A sewerage system serves 1,000 people and discharges into the creek. This stream is dammed at several points, forming pools. As a result the amount of pollution which reaches the river is slight.

Great Tonoloway Creek.—About 2 miles below Hancock is the mouth of Great Tonoloway Creek, which rises in Fulton County, Pa., and flows south. Its watershed has an area of 92 square miles and a population of 23.3 to the square mile. The next important tributary is Sleepy Creek, which rises in Frederick County, Va., and flows on the west side of Sleepy Creek Mountain. Its watershed has an area of 142 square miles and a population of 26.7 to the square mile.

Licking Creek.—Three miles below the mouth of Sleepy Creek Licking Creek enters from the north. This stream rises in Pennsylvania and flows almost directly south. It has a watershed of 187 square miles and a population of 36.1 to the square mile. The only town of importance on the stream is McConnellsburg, Pa., with a population of 579. A public water supply is derived from springs on Cove Mountain. The average daily consumption is about 20,000 gallons. There are no sewers in the town, the inhabitants depending upon privies and cesspools for the disposal of their wastes.

Back Creek.—Six miles below the mouth of Licking Creek, Back Creek enters from the south. Its watershed embraces an area of 279 square miles and has an almost wholly rural population of 30.9 persons to the square mile. The only village of note is Hedgesville, which has a population of 328. There is neither public water supply nor sewerage system at this point. From the mouth of Back Creek to that of Conococheague Creek there is only indirect pollution, the largest town being Clear Spring, Md., located on Tom's River, a branch of the Little Conococheague.

Conococheague Creek.—Conococheague Creek rises on South Mountain, in Adams County, Pa., and flows in a northwesterly direction to Scotland, Pa., where it turns and flows through a winding channel in a southwesterly direction to the Potomac near Williamsport, Md. The watershed embraces an area of 582 square miles and has a population of 45,694, or 77.5 persons to the square mile.

The South Mountain Sanatorium, a Pennsylvania State institution for the care of tuberculous patients, is located on South Mountain near Mont Alto, Pa. About 1,250 patients and attendants live at the institution. The water supply of about 100,000 gallons daily, derived from Little Antietam Creek, is treated with calcium hyperchlorite. The sewage from the institution, in daily amount about the

same as that of the water supply, is carried to a sewage-disposal plant, which consists of septic tanks, sprinkling filters, sand filters, and provisions for final disinfection by calcium hyperchlorite. The effluent is then discharged into Rocky Mountain Creek, a small tributary of the Conococheague. The next point of importance is Scotland, Pa., which is a small town without water supply and sewerage system, but is the site of the State Soldiers' Orphans Industrial School. This institution of about 475 people derives its water supply of 100,000 gallons daily from a spring near the creek. The sewage is discharged into a circular 30,000-gallon dosing tank, where it is distributed over a tract of land about 5 acres in area. The system seems to be most satisfactory for an institution of this kind.

About 6 miles below Scotland is the city of Chambersburg, Pa., having a population of 11,800. A public water supply amounting to about 1,750,000 gallons daily is derived from mountain springs in the Pennsylvania Forest Reserve near the head of Conococheague Creek. The entire town has recently been sewered, but at the time of inspection only about 3,000 persons were served by the system.

The sewage is carried to a pumping station about a mile southwest of the town, where it is pumped to a complete modern sewage-disposal plant, consisting of an Imhoff sedimentation tank, a dosing chamber, a sprinkling filter, final sedimentation tanks, and a sludge bed. (Figs. 1, 2, 3, and 4.) The plant is well maintained and operated. It discharges a nonputrescible effluent into Conococheague Creek. From 700,000 to 1,000,000 gallons of sewage are treated daily.

Conococheague Creek, as it flows through the center of the city, receives a certain amount of direct pollution, as follows:

The wash water from the plant of the Cumberland Valley Creamery & Dairy Co.; about 150 gallons a week of spent lye from Gerbig's Soap Works; about 5,000 gallons of spent dye and soap water from the Home Woolen Co.; and the waste water from two slaughterhouses. About two miles below the city is the Hollowell Paper Mill, in which strawboard is made from wood pulp. The waste consists of a large quantity of wash water which contains soda ash. The privy used by 28 employees overhangs the tailrace, which joins the creek 200 yards below the mill.

Below Chambersburg the next town of considerable size is Greencastle, Pa., with a population of 1,900. A public water supply is derived from springs about 3 miles east of the town. The average daily consumption is 125,000 gallons. The town has no sewers, cesspools and crevices in the limestone formation beneath the town being used as receptacles of sewage. The practice of emptying into limestone caverns is a bad one from a sanitary viewpoint, as is well shown by the following incident: It was stated that previous to the installation of the public water-supply system the inhabitants of

Greencastle obtained their supply from private wells. Now, the hotel near the town had a cesspool beneath the barn which had become full. It was decided to drill a hole in its bottom in order to obtain an outlet for the contents. When this was done the drill suddenly broke through into a fissure, and the contents of the cesspool ran out. Shortly afterward a man who was drawing a bucket of water from the town well in the square pumped up some of the sewage. A large number of the other wells in the town were also contaminated at the same time. The town was therefore compelled in self-defense to install a public water supply.

A few miles below Greencastle the west branch of the Conococheague Creek joins the creek proper. This stream rises about 15 miles north of Chambersburg and flows south along the east side of Tuscarora Mountain to near Mercersburg, Pa., where it turns and flows in a southeasterly direction to its junction with Conococheague Creek. For the greater part of its course the stream flows through a mountainous, wooded, almost uninhabited territory. The first point of direct pollution is at Foltz, on Buck Run, a small tributary entering the creek a few miles above Mercersburg. At Foltz is located Unger's distillery. This is a small plant, having less than 500 gallons of slop or spent mash a day. Practically all of this is fed to hogs in pens on the creek bank.

Mercersburg, Pa., with a population of 1,410, has a public water supply derived from Buck Run above Foltz. The town is partly sewered, one line being owned by the municipality and two by private companies. The sewage is discharged untreated into the small creek which flows through the town and meets Conococheague Creek about 2 miles to the east. The Mercersburg Academy, with about 450 persons, obtains its water supply and discharges its sewage into the same creek as does the town. The tannery of the W. D. Byron & Sons Co. (Inc.) is located on the creek in the town. This plant tans from 100 to 300 large hides per day, and has about 100,000 gallons daily of waste liquid. The wastes consist of spent tan liquor, soak liquor, limewater, and wash water. They are discharged into a pool in the tanyard, the contents of which are discharged into the creek at night. Some of the liquid, however, seeps into the stream at all times. As a result the water is rather highly colored and has an offensive appearance.

Below the mouth of the west branch the Conococheague flows in a winding course, receiving no direct pollution until just before it enters the Potomac River at Williamsport, Md., a town with a population of 1,511, without a public water supply or a sewerage system. A water supply, however, is soon to be installed. A tannery, owned by the W. D. Byron & Sons Co. (Inc.), is located at this point. Liquid wastes, consisting of 60,000 gallons a day of spent tan liquor, lime-

water, soak water, wash water, aniline dye, and sumac, are discharged into a ditch which leads into the creek.

Opequon Creek.—About 9 miles below Williamsport, Opequon Creek enters the Potomac River from the south. This stream rises near Stephens City, Va., and flows in a northeasterly direction, for a distance of about 35 miles, to the Potomac. It has a watershed of 346 square miles, and a population thereon of 82 persons to the square mile. On Abrams Creek, a small tributary near its source, is located Winchester, Va., a thriving city, with a population of 5,864. Winchester has a public water supply derived from Rouses Spring, southeast of the town. The average daily consumption is about 1,000,000 gallons. A plant for treating the water with liquid chlorine is soon to be installed. The entire town is served by a sewerage system, which also receives the liquid wastes from the Lewis Jones Knitting Co. and the Virginia Woolen mill. The sewage is carried to a point below the water pumping station and there treated in a sewage-disposal plant which consists of a screen chamber, a dosing tank, four sand filters, and a sludge bed. (Fig. 5.) The filters are run in pairs and are scraped once a week. The sewage is very highly colored by the woolen-mill wastes, which also contain large amounts of lint. This latter material has a tendency to clog the surface of the beds. The sludge bed is used for drying the material that collects in the screen chamber. The effluent which discharges into a branch of Abrams Creek seems to be of good quality, judging by its appearance and by the absence of putrefaction in the stream below the plant.

Below Winchester there is no more direct pollution until the city of Martinsburg, W. Va., is reached. This town, located on Tuscarora Creek, about 2 miles above where it joins the Opequon, is a progressive, growing community, with a population of 10,698. There is a municipally owned public water supply, derived from springs about a mile south of the town. This supply had been considered entirely safe from a sanitary standpoint until early in 1914, when officers of the United States Public Health Service who were making an intensive study of sanitary conditions in Berkeley County found, on inspection, that the springs were exposed to the direct drainage from a barn and an open insanitary privy, and that the water contained *B. coli.* The barn was immediately moved and the privy converted into one of sanitary type. At the request of the city authorities, Sanitary Engineer Letton of the service was called in, and at his suggestion a temporary plant was installed for disinfecting the water with calcium hypochlorite. Since that time the water delivered to the town has been free from pollution. It is planned shortly to replace the temporary plant by a permanent one. The average daily consumption is about 1,430,000 gallons.

There is no sewerage system in Martinsburg, but it is intended to vote upon the subject of constructing one in the near future. Tuscarora Creek flows through the town and receives the flow from numerous springs which issue from the limestone. A deep ravine leads north from the creek. In the bottom of this ravine a circular concrete sewer has been constructed for a considerable distance, for the purpose of carrying off storm water and the wastes from two knitting mills, but there are undoubtedly many sewer connections along its entire length. At the head of the ravine is located the Interwoven Knitting mill. The waste from this mill, consisting of spent dye and wash water to the amount of about 25,000 gallons daily, is discharged into a tank having a capacity of 18,000 gallons. From this tank the liquid enters the above-mentioned sewer. The sewage of the employees is discharged into a cesspool. A little farther down the ravine is the mill of the Crawford Woolen Co. This company, which has about 300 employees, discharges its spent dyes and wash water directly into the sewer. The sewage of the employees goes into a large cesspool. The discharge from the sewer has an offensive appearance and odor and gives to Tuscarora Creek a high color, which persists until after it has commingled with the waters of Opequon Creek. The Hannis distillery is located some distance above the point where the sewer discharges into Tuscarora. At this point has been discharged the water separated from the spent mash. This waste has caused nuisances in the past, but since July 1, 1914, the manufacture of whisky has been prohibited by statute in the State of West Virginia. Typhoid fever has been prevalent in Martinsburg for years. This is probably due to the fact that insanitary privies and cesspools have been used almost without exception. Public sentiment, however, has been aroused and it is hoped that conditions will be improved. No direct pollution enters Opequon below Martinsburg.

POTOMAC RIVER FROM OPEQUON CREEK TO ANTIETAM CREEK.

About 20 miles below the mouth of Opequon Creek is the town of Shepherdstown, W. Va., with a population of 1,070. The town has neither water supply nor sewerage systems, the inhabitants depending upon wells and privies, of which the latter contribute more or less indirect pollution to the river. Five miles below Shepherdstown Antietam Creek enters the Potomac from the north. This stream, which rises in the South Mountain in Franklin County, Pa., drains a watershed of 289 square miles, with a population of 145.8 persons to the square mile. The first town of importance is Waynesboro, Pa., a rapidly growing community with a population of 7,198. The town has a public water supply derived from a small stream on the

mountain 6 miles east of Waynesboro. The average daily consumption is about 1,300,000 gallons. There is no sewerage system in the town for the following reason: The entire place is underlaid by a limestone formation containing numerous fissures, to which a majority of the buildings in the town are connected. There are a number of large machine factories in Waynesboro, and these discharge the sewage of their hundreds of employees into fissures in the rock. While such practice is a convenient one for this community, it undoubtedly has insanitary effect upon the wells and springs of the country for some distance below Waynesboro. About a mile southeast of Waynesboro Red Run joins the east branch of Antietam Creek. Red Run receives the indirect drainage from Rouzesville, Pa., and from the summer-resort district in which are located Pen Mar, Buena Vista Springs, Cascade, Highfield, and parts of Blue Ridge Summit, Monterey, and Charmian. These latter places are partially served by public water supplies. Cesspools and privies, however, are the only methods used for the disposal of sewage. Rouzesville has a public water supply derived from a small stream on the near-by mountain. It has no sewerage system, but depends on cesspools and crevices in the limestone.

The next point where pollution occurs is at Hagerstown, Md. This is the third largest city in Maryland, and in the Potomac River watershed. Its population was 16,507 in 1910, and it is growing at the rate of about 300 per year. It has a public water supply furnished by the Washington County Water Co. The supply is derived from an impounded stream in Warners Gap Hollow on South Mountain, about 11 miles east of the city. The average daily consumption is about 2,500,000 gallons. The water is treated at the reservoir with calcium hypochlorite. In years of low rainfall this supply does not furnish enough water to meet the demand, such a condition having occurred three times in the last five years. In order always to furnish enough water, the company has built a rapid sand filtration plant on Antietam Creek, 2 miles east of town. This plant has a capacity of 4,500,000 gallons daily. The water is coagulated with sulphate of aluminum, settled, filtered, and then treated with calcium hypochlorite. There is no domestic sewerage system in Hagerstown. A small run which bisects the town has been covered for a considerable distance and acts as a storm sewer. To this run have been connected, unlawfully, a great number of domestic sewers from buildings along its course, and into it are also discharged the wastes from the following establishments: Condenser water and water used in washing kegs from the Hagerstown brewery; about 70,000 gallons daily of dilute bleach and soda-ash solutions from the J. C. Roulette & Sons Co. (this waste undoubtedly has a beneficial

effect on the stream, as the odor of bleach was quite noticeable at the outlet of the sewer); about 10,000 gallons of spent-dye liquor per day from the Blue Ridge Knitting Co. About 1 mile up Antietam Creek from the filter plant of the water company is the mill of the Antietam Paper Co. This company, which makes paper from old newspapers by the soda process, discharges about 100,000 gallons per day of dirty water containing a small amount of bleach and soda ash.

The only other towns of importance on this stream are Sharpsburg, Md., and Keedysville, Md., having a population, respectively, of 960 and 367. Neither town has a water supply or sewerage system. Sharpsburg is the station for visitors to the Antietam battle field and is of importance because of their large number.

The sanitary survey of the basin up to this point has given evidence of continuous, and in places concentrated, pollution of the river, but when the great dilution is considered it was not anticipated that this pollution would prove to be extreme. The following bacteriological findings confirm this conception (Table 3). The presence of *B. coli* in a majority of 1 c. c. samples and in an occasional 0.1 c. c. sample closely corresponds to the conditions found at the inlet of the Washington water supply, which is interpreted as excluding any considerable introduction of pollution between Harpers Ferry and Great Falls. Water polluted to this extent, while of course unfit for domestic use without preliminary treatment, nevertheless furnishes an acceptable supply when such treatment is adequately applied.

TABLE 3.—*The results of bacteriological examination of water in the vicinity of Harpers Ferry, Md., May, 1914.*

Place and date.	Sample No.	Bacteria per c. c.		*B. coli* in broth.			
		Agar.	Gelatin.	10 c. c.	1 c. c.	0.1 c. c.	0.01 c. c.
West Virginia side of bridge: May 5, 1914	1	10,000	20,000	......	+	......	......
Canal at Harpers Ferry: May 5, 1914	2	4,800	13,000	......	......	+	......
Maryland side of bridge: May 5, 1914	3	500	3,800	+	......	......	......
Shenandoah, West Virginia end of bridge: May 5, 1914	4	1,600	1,800	......	+	......	......
Shenandoah, above Harpers Ferry, West Virginia side: May 5, 1914	5	900	1,500	......	+	......	......
Shenandoah at Harpers Ferry, Virginia side of bridge: May 5, 1914	6	5,300	5,500	......	+	......	......
Shenandoah at Harpers Ferry, Virginia side of bridge: May 6, 1914	7	2,500	4,800	......	+	......	......
Shenandoah at Harpers Ferry, middle of bridge: May 6, 1914	8	3,300	4,000	......	+	......	......
Shenandoah at Harpers Ferry, West Virginia side of bridge: May 6, 1914	9	5,500	6,800	......	+	......	......
Shenandoah above Harpers Ferry, West Virginia side: May 6, 1914	10	1,400	2,300	......	+	......	......

TABLE 3.—*The results of bacteriological examination of water in the vicinity of Harpers Ferry, Md., May, 1914*—Continued.

Place and date.	Sample No.	Pacteria per c. c.		*B. coli* in broth.			
		Agar.	Gelatin.	10 c. c.	1 c. c.	0.1 c. c.	0.01 c. c.
Canal at Harpers Ferry: May 6, 1914	11	5,000	6,800	......	......	+	......
Potomac, Maryland side of bridge: May 6, 1914	12	6,500	11,000	......	......	+	......
Potomac, Maryland side of bridge at middle: May 6, 1914	13	1,300	5,700	......	......	+	......
Potomac, West Virginia side of middle of bridge: May 6, 1914	14	1,100	2,000	......	......	+	......
Potomac, Virginia side of bridge: May 6, 1914	15	2,000	3,800	......	+	......	......
Between Cumberland and Harpers Ferry.							
Potomac above South Branch: May 4, 1914	Q	1,000	6,400	......	+	......	......
Potomac South Branch above North Branch: May 4, 1914	R	1,000	4,700	......	......	+	......
Little Cacapon: May 4, 1914	S	375	5,000	+	......	......	......
Potomac above Magnolia: May 4, 1914	T	1,000	4,300	+	......	......	......
Potomac at new bridge, Magnolia: May 4, 1914	U	1,400	9,300	+	......	......	......
Potomac at Western Maryland Ry. bridge below Magnolia: May 4, 1914	V	7,800	9,100	......	......	+	......
Well supplying Bennet & Talbot construction camp: May 4, 1914	W	3	20	−	......	......	......
Well supplying H. S. Kerbaugh construction camp: May 4, 1914	X	5	80	−	......	......	......

CHESAPEAKE & OHIO CANAL.

The following quotation is from The Potomac River Basin, Department of the Interior, United States Geological Survey, 1907:

The Chesapeake & Ohio Canal, which commences at Cumberland, lies on the Maryland side of the Potomac and pursues the immediate valley of the river to a point 1 mile below Pawpaw, where it passes through a spur of Town Hill by means of a tunnel 3,636 feet long and of circular cross section 27 feet across. This tunnel saves about 6 miles. The total rise, from the level of midtide at Georgetown to the Cumberland Basin, is 609.7 feet. This ascent is broken by 74 lift locks and a tide lock that connects Rock Creek Basin with the Potomac. The canal has a depth of 6 feet throughout, and from Georgetown to Harpers Ferry, 60 miles, it is 65 feet wide at the surface and 41 feet at the bottom. From Harpers Ferry to Dam No. 6, 47 miles, the width at the surface is 60 feet and at bottom 36 feet. From Dam No. 6 to Cumberland, 50 miles, the surface width is 55 feet and the bottom width 31 feet. The average lift of the locks is a little in excess of 8 feet, though there are thirteen 10-foot locks and four 6-foot locks. The locks are 100 feet long and 15 feet in the clear, and pass boats carrying 122 tons of 2,240 pounds. The canal is fed with water at eight different points. The first is at the Beal mill race, in Cumberland, which is connected by gates with Wills Creek at the dam near the tannery of the United States Leather Co.

The enormous amount of sewage which this race receives is to a large extent deposited as sludge in the head basin of the canal. This action is probably facilitated by the nature of the water received at the second supply point, the head gates of the canal. This water is, as a rule, largely from Wills Creek, mixed with considerable water from North Branch, though in times of low water the entire flow of both North Branch above Dam No. 7 and Wills Creek goes down the canal.

The Wills Creek water is heavily polluted by mine waters, and therefore contains considerable quantities of iron and sulphuric acid, which are precipitating elements, as is the lime of North Branch. So great is the accumulation of precipitated sewage in the head basin that the canal company finds it necessary to dredge it out every other spring. When this is done, the sludge is distributed over the towpath and river side of the embankment. It becomes very hard and most of it remains in place, though some of it is carried off by the river. In the winter, after the water is drawn off from the canal, the contents of the race discharge into the head basin as usual, but instead of continuing down the canal, as when the canal is in use, they return to the river near the foot of the basin and below Dam No. 7. This first supply is not properly a part of the works of the canal. The precipitating action continues for 51 miles down the canal to the third supply point, Dam No. 6, where the water in the canal is said to be much clearer than at Cumberland.

Dam No. 6, below Greenspring, admits river water, which to a large extent comes from South Branch, and hence is usually of better quality than the river water at Cumberland, and by dilution greatly improves the water in the canal. From Dam No. 6 to Dam No. 5 the distance is 29 miles. About 6 miles above Dam No. 5 the canal passes through what are known as Little and Big Pools. These were originally high-water channels of the river, which have been incorporated into the canal. Big Pool is 2 miles long. The occurrence of these pools is noted, because the current through them must necessarily be very small, and so gives opportunity for sedimentation of material suspended in the canal water, and also because they must add to the time it takes the water to complete its passage through the canal from Cumberland to the river. The canal and the river unite half a mile above Dam No. 5, and in the half-mile stretch above the dam the canal and river waters are thoroughly mixed. At Dam No. 5 the canal resumes its separate course, and a fourth point of water supply is established.

From Dam No. 5 to Dam No. 4, the fifth point where water is received by the canal, the distance is 21½ miles. About 4½ miles above Dam No. 4 the canal reenters the river, and continues united with it for 3.3 miles, to a point 6,000 feet above the dam. In this distance the waters of the canal and river have become thoroughly mixed, and it is well to remember that this dam is but 67½ miles above Great Falls. From Dam No. 4 the canal continues 23 miles to Dam No. 3, at Harpers Ferry, the sixth point of water supply. Dam No. 2, half a mile east of Seneca Falls and 40 miles below Harpers Ferry, is the seventh and last point of water supply until Dam No. 1 is reached at Little Falls.

Throughout its length the canal is built on the surface of the land, and so receives little ground water; in fact, the water has a tendency to seep out through the canal banks and, in places, to make the farm lands too wet to be successfully cultivated. The current in the canal is very variable, changing in its different sections and with the stage of the river. Perhaps it would be correct to assume a current of 1 mile an hour in normal sections. At times of flood portions of the canal are under water.

Two expensive aqueducts carry the canal over Conococheague Creek and Monocacy River. The myriad little runs that come down from the hillsides to the river are excluded from the canal by means of passages made for them beneath the canal through masonry culverts. Thus these streams find direct entrance to the Potomac, except three, which enter Big Pool, and a few dry runs, the most important of which are one a little east of Monocacy River, one just above Harpers Ferry, and one 2 miles below Dam No. 6.

Every winter the water is drained off from the canal and its service discontinued. The length of the canal season is usually eight to nine months, and repairs are made every spring before the canal is reopened. It is not found necessary to clean out the canal on account of suspended matter deposited during the season's use, but certain points on the canal need rather frequent dredging because of earthy materials that is brought in over its banks by water flowing over cultivated ground and in other ways. The canal company has no sanitary regulations, and the crews of canal boats use the canal as a receptacle for feces and for kitchen offal. A few of the privies of the lock keepers overhang the canal, but the feces do not get into the river except in times of freshet. The canal company has succeeded in abolishing all but two or three of the other privies which overhang its line, and these, it is expected, will soon be removed. During the season of 1905 but one man employed on the canal boats was known by the officials of the company to have suffered from typhoid fever.

The canal has changed but little, and the above accurate description is therefore applicable at this time as a general survey of conditions. There have, however, been changes near Cumberland which affect the canal. The completion of the tunnel which drains the extensive mines around Eckhart has increased enormously the acid wastes in Wills Creek, from which is derived almost all of the water which flows into the head basin of the canal, and as a result of this the sedimentation has been greatly increased. The change in chemicals used at the paper mills at Luke may also contribute to increased sedimentation. Because of the important action upon the sewage of Cumberland, this basin is a valuable asset in the purification of the river, but below this point the effect of the canal upon the character of the river is slight. The amount of pollution received is small, the total flow is small, and the canal is merged with the river at several points.

POTOMAC RIVER FROM ANTIETAM CREEK TO SHENANDOAH RIVER.

Elk Branch, a small stream which receives the indirect pollution of Shenandoah Junction, enters the Potomac a mile above Harpers Ferry. Five miles below the mouth of Antietam Creek the Shenandoah River joins the Potomac. On the neck of land between these is located Harpers Ferry, W. Va., a town which has a population of 766. There is no public water supply in Harpers Ferry, the inhabitants depending on private wells for water. The Hilltop Hotel has a water supply from a deep well, and discharges its sewage over a bluff, where it ultimately is washed into the Potomac. The Balti-

more & Ohio station has a sewer discharging into the Potomac beneath the bridge. Two mills which manufacture wood pulp are located in Harpers Ferry—one on the Potomac and one on the Shenandoah. The pulp is made by the mechanical or grinding process and all the waste material is burned.

SHENANDOAH RIVER.

South Fork.—The Shenandoah is the largest tributary of the Potomac, its watershed embracing an area of 3,058 square miles and supporting a population of 43.7 persons to the square mile. The Shenandoah River is formed at Riverton, Va., by the confluence of the North Fork and South Fork. The South Fork is in turn formed by the confluence of the North River, Middle River, and South River near Port Republic, Va.

South River rises in Augusta County, Va., and flows northeast. The first points of pollution are at the towns of Basic City, Va., and Waynesboro, Va., located opposite each other on the east and the west banks of the river, and having populations of 1,623 and 1,389, respectively. Basic City has a public water supply obtained from the Basic City Lithia Spring. The water from the spring flows by gravity to a pumping station, where it is forced to a reservoir on the hill above the town. The average daily consumption is about 200,000 gallons. A system of sewers to serve about 50 per cent of the population is being constructed. At the present time a few private sewers discharge into the river. Two plants for obtaining tanning extract from chestnut wood are located in Basic. The condenser water from these plants, which contains a small amount of extract, is discharged directly into the river.

Waynesboro has a public water supply derived from Baker Spring, just south of the town. There is no public sewerage system, but about three-fourths of the town is served by private sewers, which discharge directly into the river.

Below Basic, the only point of importance on the South River, is Grottoes, Va. At this point is located the celebrated Weyer's Cave, which annually attracts thousands of visitors. The town has neither water-supply nor sewerage systems. There is a large summer camp on the river near the cave, which undoubtedly contributes a certain amount of indirect pollution.

Middle River, which joins North River near Port Republic, rises in the mountains south and west of Staunton, Va., the tributaries and main river joining in a branching, tree-shaped figure. The only important place on this stream is Staunton, Va., a rapidly growing town having a population of 10,604. A public water supply owned by the municipality is derived from a number of springs located just west of the town. The average daily consumption is about

1,300,000 gallons. About 50 per cent of the town is served by a "separate system" of sewers, which discharge at various points into Lewis Creek, a small stream that flows through the city. Through the central part of the town the stream is arched over, but this is discontinued at a point near the Baltimore & Ohio Railroad station. At this point the stream is simply an open sewer, which has an offensive appearance and gives off unpleasant odors.

The following schools are located in Staunton, and during the school year the population is increased accordingly: Staunton Military Academy, 450 students; Mary Baldwin Seminary, 350 students; Stuart Hall, 200 students; Business College, 200 students; and the Virginia School for the Deaf and Blind with 250 students. All of the above institutions, with the exception of the last, are supplied with water from the town supply and connected with the public sewerage system. The school for the deaf and blind has a connection with the public water supply for fire protection, but water for domestic purposes is obtained from a private supply, derived from a spring which yields about 30,000 gallons per day. The sewage from the school is discharged into Lewis Creek. Another State institution, the Western State Hospital, with about 1,500 patients and attendants, is located in Staunton. Its water supply of about 125,000 gallons daily is obtained from the town supply. The sewage from the institution is discharged into a small tributary of Lewis Creek which flows through the grounds. Inasmuch as the grounds are used as a park in which the patients exercise, it would seem much better to carry the sewage through a pipe line directly into Lewis Creek.

North River rises in the northwest corner of Augusta County, Va., and flows in a general northeasterly direction, its tributaries as a rule entering from the north. The upper part of the watershed being rough and mountainous is given over almost wholly to lumbering. The first pollution of note is at Bridgewater, a town with a population of 859. A municipally owned public water supply and a complete sanitary sewerage system have just been installed at this point. The water supply is derived from springs west of the town. The consumption is small at the present time, but connections are rapidly being made and more water is being used every day. The sewers discharge directly into North River about 1,000 feet below the town.

About 4 miles below Bridgewater, Cooks Creek enters from the north. This stream receives the flow of Blacks Run, a small tributary which rises near Harrisonburg, Va., and receives the drainage therefrom.

Harrisonburg, with a population of 4,879, has a municipally owned water supply derived from Dry River, about 13 miles west of the

town. The average daily consumption is about 600,000 gallons. The town is almost completely sewered and the sewage is carried through a line of pipe to a point about 2 miles south of the town, where it is discharged into Blacks Run.

The tannery of the J. P. Houck Tanning Co. is located in Harrisonburg. This establishment uses about 100,000 gallons of water a day, obtained from the old "town spring." The waste liquid, consisting of spent-tan liquor, soak liquor, wash water, and limewater, is discharged into the town sewer. When the sewer was extended to the creek it was intended to construct a complete sewage-disposal plant, as it was evident that there was insufficient flow in Blacks Run to care for the sewage without causing a nuisance. The project was held up by property owners in the vicinity of the proposed plant, and the sewage has been discharged directly into the creek. This has caused a great deal of trouble. The tannery waste gives the sewage a dark color, and at the point of discharge a pool has been formed, which is covered with scum and is actively septic. (Fig. 6.) The odor from the stream where the valley pike crosses it is very disagreeable. It is evident that this condition should not be allowed to continue.

South Fork below Port Republic.—The first important point on the South Fork below Port Republic is Elkton, Va., which has a population of 873. A public water supply, owned by the Elkton Lithia Spring Water Co., is derived from the Elkton Lithia Spring, about a mile east of town. About 900 persons are supplied with the water. A sewer, serving about 15 houses, discharges directly into the river, as does a private sewer from the Elkton Hotel. A tannery, owned by J. R. Cover & Sons, is located in Elkton on Elk Run, a small stream flowing through the town. About 112 hides are being handled daily, but it is intended to increase this number next year to 165. The wastes, consisting of spent-tan liquor, soak water, wash water, and limewater, to the amount of about 30,000 gallons, to which is added several times this amount of condensed water a day, are discharged into Elk Run. The creek, clear and sparkling above the tannery, is converted into a black, greasy, foul-smelling run by these wastes, and as it flows through the center of the town it presents an extremely unpleasant appearance, to say the least.

The next point of pollution is the town of Shenandoah, with a population of 1,431, located about 6 miles north of Elkton. Shenandoah has a public water supply, derived from the South Fork, serving about 1,600 persons. The water is not treated in any way, and is said to be always turbid following rains, besides being colored by the tannery effluent at Elkton. This is a condition which should not be allowed to continue. While it is stated that typhoid fever is not

now unduly prevalent in Shenandoah, the town is undoubtedly subject to the potential danger of a serious outbreak of typhoid fever at any time.

Sixteen miles below Shenandoah is Luray, Va., with a population of 1,218. A municipal water supply derived from two small streams on the mountain east of the town is in operation. It is said that about 2,500 persons are supplied with the water. There is no public sewerage system, but about 500 persons are served by private sewers discharging into Hawkesbill Creek, which divides the town into two parts. This stream also receives the wastes from two tomato canneries and from the tannery of the Deford Co. At this factory 254 large hides, about 84 per cent of the capacity of the plant, are tanned daily. The wastes, which consist of soak liquor, limewater, wash water, and spent tan liquor, to the amount of 150,000 gallons daily, are distributed into either one of two ponds, 100 feet in diameter by 3½ feet deep and 62 feet in diameter by 2½ feet deep, respectively. The effluent from the ponds is discharged directly into the creek. The sediment which accumulates in the ponds is periodically removed and used as a fertilizer. For about 2 miles below this tannery the creek presents a very unsightly appearance, due to accumulations of sediment along its course. The discoloration persists from this point to the junction of Hawkesbill Creek with the Shenandoah. This tannery has been selected by the service for experimental studies of methods of disposal of wastes of this character.

North Fork of the Shenandoah River.—The North Fork rises in West Virginia just across the State line from the northeast corner of Rockingham County, Va. It flows in a southeasterly direction to a point near Broadway, Va., where it turns and flows northeast to Strausburg, at which place it again turns southeast to its junction with the South Fork at Riverton, Va.

The first town causing pollution is Mount Jackson, Va., which has a population of 479. There is a municipally owned public water supply at this point derived by gravity from springs on Massanutten Mountain, east of the town, by which about 400 persons are supplied. The entire town is sewered, the sewage being discharged into the river and a small creek through four outlets.

Eight miles below Mount Jackson is the town of Edinburg, with a population of 574. A public water supply is derived by gravity from springs 4 miles east of the town. About 50,000 gallons are used daily, of which quantity the Southern Railroad Co. takes 35,000 gallons. In times of drought the railroad is supplied with water pumped from Stony Creek. There is no public sewerage system, but about 100 persons are served by private sewers which discharge into Stony Creek.

Six miles below Edinburg is the town of Woodstock, Va., with a population of 1,314. There is a municipally owned water supply derived by gravity from springs on Massanutten Mountain. The town has no sewers, cesspools and privies being depended upon for sewage disposal. The creamery of the Chapin-Sacks Co. is located in Woodstock on a small creek, into which it discharges a large amount of condensed water, some milk, and wash water.

The next point to be noted is Strasburg, Va., with a population of 769. The town has a public water supply, derived from a stream on Massanutten Mountain, which supplies about 1,200 persons. There is no public sewerage system, although about 30 houses have private sewers which discharge into small tributaries of the river.

No more direct pollution reaches the river before its junction with the South Fork. Between the two streams is Riverton, Va., a small town which obtains its water supply of about 100,000 gallons a day from Front Royal, Va.

Just below Riverton, Happy Creek enters the Shenandoah River from the south. On the creek a short distance from its mouth is the town of Front Royal, Va., with a population of 1,133. There is a municipally owned water supply at this point derived from Happy Run, near Chester Gap. The average daily consumption of water is about 400,000 gallons, which supplies about 3,000 persons. About a year ago Front Royal had an epidemic of typhoid fever, the source of which was traced to the water supply, following which the character of the supply was materially improved. A number of the L. R. S. type of sanitary privies were installed along the roads leading through the watershed, and a modern rapid sand filtration plant was constructed. (Fig. 7.) The water, after filtration, is treated with calcium hypochlorite.

A considerable portion of the watershed is embraced in the grounds of the Front Royal remount depot of the United States Army. The station buildings have a water supply derived from springs. The sewage is to be treated in septic tanks and sprinkling filters, and the effluent discharged into Happy Run, just below the reservoir of the Front Royal water supply. Sanitary privies have been constructed at numerous points throughout the reservation. There is no public sewerage system in Front Royal, but the installation of one is under consideration. A few private sewers discharge into the creek, as does the effluent from three septic tanks in which the sewage of the Randolph-Macon Academy is treated. This school has about 200 students who use daily about 9,000 gallons of water obtained from the town supply.

The next town of importance is Berryville, Va., with a population of 876. This town, located on Lewis Creek about 4 miles from its mouth, has a public water supply derived from mountain streams

east of the Shenandoah River. There is no sewage system, the inhabitants depending on cesspools and privies to receive the wastes.

Below Berryville there is no more direct pollution until Evitts Run enters the river. On this small stream is Charles Town, W. Va., with a population of 2,662. A public water supply, owned by the Charles Town Water Co., is derived from a covered spring near Evitts Run. The average daily consumption is about 400,000 gallons. In the summer months, during the period of low rainfall, it is customary to use some surface water to augment the supply. This surface water and the spring itself are liable at any time to pollution of a dangerous character. At the request of the health officer of Charles Town the writer made an inspection of the supply and discused it before the town council. A representative of the water company was present at the meeting and agreed to install immediately a plant for treating the water with calcium hypochlorite. There is no sewerage system in Charles Town, the inhabitants using privies and cesspools.

Four miles below Charles Town, on Flowing Run, is Halltown, Va. At this place is a large paper mill making cardboard from old paper. The only waste from this plant consists of dirty water used in washing the paper. This is the last point of pollution above the mouth of the river at Harpers Ferry.

POTOMAC RIVER BELOW THE SHENANDOAH RIVER.

About 4 miles below Harpers Ferry is the town of Weverton, Md., and about a mile below it is Knoxville. These are both small places and contribute only indirect pollution to the river. At Weverton is the Savage Distillery, a small plant. The spent mash is piped into a wooden tank, from which it is sold to farmers for feed; a certain amount, however, spills on the ground and finds its way into the river.

A few miles below Knoxville is Brunswick, Md., a town having a population of 3,721. At this point are located the shop and transfer yards of the Baltimore & Ohio Railroad. There is a public water supply derived from a deep well, about 60,000 gallons being used daily. A few houses and the Baltimore & Ohio buildings are supplied with raw Potomac River water, which is pumped by the railroad company. There is no sewerage system in Brunswick, but a great many people have private lines leading to one of the four ravines which traverse the town. Sewers from the office buildings of the railroad company, the Y. M. C. A., and the shops also discharge into these runs. The town is built on the side of a steep hill, and during rains the pollution must be washed quickly into the Potomac, thus constituting direct pollution.

About 5 miles below Brunswick, Catoctin Creek enters from the north. This stream has a watershed of 112 square miles and a population of 58.4 persons to the square mile. The first town of importance is Middletown, Md., with a population of 692. There is a municipally owned public water supply at this point derived from a spring on a near-by mountain. There is no public sewerage system, but a number of houses have sewers which empty into the town run.

The next point of importance is Burkittsville, Md., having a population of 228. The town is located on Middle Creek, a branch of Broad Run, which joins the Catoctin 5 miles above its mouth. A public water supply owned by the Burkittsville Water Co. is derived from a spring on South Mountain, from which about 50 persons are supplied with water. The distillery of the Horsey Outerbridge Co. is located at this point. About 6,000 gallons of water from the spent mash are discharged daily during the winter months into Middle Creek.

Five miles below the mouth of Cacoctin Creek are the small towns of Point of Rocks and Washington Junction, Md., which contribute only in direct pollution to the river. About 6 miles below these towns the Monocacy River enters the Potomac River from the north.

MONOCACY RIVER.

Rock Creek, Pa.—The Monocacy River has a watershed of 962 square miles, on which there live 77.9 persons to the square mile. It rises in Adams County, Pa., in three branches—Rock, Marsh, and Toms Creek. Near the source of Rock Creek is Gettysburg, Pa., with a permanent population of 4,030. The Gettysburg battle field, which has been made into a national park, attracts thousands of visitors annually, so at times the population is considerably augmented. The town has a privately owned public water supply, derived from Marsh Run, about 4 miles to the southeast. At this point there is a rapid sand filtration plant, having a capacity of 1,000,000 gallons per diem. The water, after filtration, is treated with calcium hypochlorite. The average daily consumption is about 400,000 gallons. The town is completely sewered by a system of sanitary sewers. The sewage is discharged into a small septic tank and the effluent from this enters Stephens Run, a small creek, about 200 yards above its junction with Rock Creek.

During the reunion encampment in 1913 the State health department installed a plant for treating the sewage effluent with calcium hypochlorite. After the encampment the plant was given to the city. It was not in operation, however, at the time of inspection. Below the point of sewage discharge, Jennings Run is an open sewer in a foul condition. The evidence of the sewage in Rock Creek below Jennings Run is also very striking.

From below Gettysburg to the place where Rock Creek joins Marsh Creek to form the Monocacy there is no direct pollution. The only probable points of pollution on Marsh Creek are at McKnightstown, Pa., where there is a small tannery, at present not in operation, and at Ortanna, Pa., where a large apple cannery is located, from which there may be some waste in the canning season.

Toms Creek.—Near the headwaters of Toms Creek is located the Maryland Tuberculosis Sanitorium, with a population of about 550. The institution has a water supply derived from a covered spring and from six wells. The sewage from the buildings is discharged into a large septic tank, and the effluent from this runs into a series of underground tiles. The system gives great satisfaction, the sewage being kept out of sight during the entire process of disposal. At times the effluent from the septic tank is run on the surface of the ground and used to irrigate crops which are grown on the land in which the tile is laid.

Farther down Toms Creek is the town of Emmitsburg, Md., with a population of 1,054. There is a privately owned public water supply derived from Turkey Creek near its source. About 1,000 persons in the town and 600 in St. Joseph's Academy are supplied. There is no public sewerage system in Emmitsburg, but a number of private sewers discharge into Flat Run, a small stream east of the town.

St. Joseph's Academy, also the location of the Mother's House of the Sisters of Charity of the United States, has a private sewer discharging into Toms Creek. Two miles southwest of this point is located St. Mary's College, a school for boys. This institution has a water supply derived from a spring and a system of sewers which discharge into a small tributary of Toms Creek. There are about 300 students at the school during the school session.

Piney Creek.—About 2 miles above the mouth of Toms Creek Piney Creek enters from the east. This stream rises near Littlestown, Pa., a town with a population of 1,347. There is a municipally owned public water supply at this point derived from two deep wells east of town. There are about 850 persons supplied with the water, the average daily consumption being 95,000 gallons. There is no sewerage system in Littlestown, privies and cesspools being used for the disposal of wastes.

Eight miles below is Taneytown, Md., with a population of 842. A municipal water supply is derived from drilled wells. The average daily consumption is about 40,000 gallons. A private sewer from the hotel empties into a small branch of Piney Creek, while the remainder of the town is served by privies and cesspools.

Double Pipe Creek.—About 6 miles below the mouth of Toms Creek Double Pipe Creek enters from the east. This stream is

formed 2 miles from its mouth by the confluence of Little Pipe Creek and Big Pipe Creek. There is no important pollution on the latter stream.

Little Pipe Creek rises near Westminster, Md., a town located on the Potomac watershed divide, with a population of 3,295. A public water supply, owned by the Consolidated Public Utilities Co., is derived from springs and wells. The average daily consumption is about 280,000 gallons. There are no sewers in Westminster, the wastes being disposed of in privies and cesspools.

Eight miles below Westminster is the town of New Windsor, which has a population of 446. A municipal public water supply is derived from springs 3 miles south of the town. There are no sewers.

Five miles below is Union Bridge, Md., with a population of 804. A municipally owned public water supply is derived from deep wells. The average daily consumption is about 140,000 gallons. One of the wells having shown contamination, a plant was recently installed for treating all water with chlorine gas. There are no sewers in Union Bridge, cesspools being the common method of sewage disposal.

Hunting Creek.—About 8 miles below the mouth of Double Pipe Creek Hunting Creek enters from the west. On this stream is located Thurmont, Md., with a population of 903. A public water supply, owned by the Mechanicstown Water Co., is derived from High Run, a small branch of Hunting Creek. There are no sewers in Thurmont.

Walkersville.—Below Thurmont, on Glade Creek, a small tributary, is Walkersville, Md., having a population of 582. The Walkersville Water Co., which derives its supply from springs near the head of Gape Creek, furnishes water to the town, supplying about 450 persons. There is no sewerage system in Walkersville, the inhabitants using privies and cesspools for the disposition of their wastes.

Carroll Creek.—A few miles below the mouth of Glade Creek Carroll Creek enters the Monocacy. On this stream, 2 miles above its mouth, is the town of Frederick, Md., which has a population of 10,411. Frederick has a municipally owned public water supply derived from Tuscarora and Fishing Creeks, northeast of the town. The average daily consumption is about 2,500,000 gallons. The town has no general sewerage system for domestic sewage, but several sewers discharge into Carroll Creek. It is illegal for sewage to be emptied into these streams without being first passed through a septic tank. The tannery of Birely & Sons is located on the bank of Carroll Creek. About 60 hides are tanned weekly. It is alleged that there are no wastes from this establishment, but undoubtedly

some liquid escapes into the stream. The Union Knitting Mills discharge a large amount of spent bleach and dye liquor, as well as the sewage from their 200 employees, into the creek. The Whtie Cross Milk Co. discharges a certain amount of wash water containing some milk. The Monocacy Valley Co. during the canning season has a small amount of waste, consisting mostly of wash water from peas and corn.

Two miles above Frederick is the Monte View Hospital and Almshouse, with 200 inhabitants, for which water is obtained from the Frederick supply. The sewage is passed through a septic tank and then discharged into Carroll Creek. This stream below the city presents a very disagreeable aspect, being nothing less than an open septic sewer. No appreciable pollution reaches the Monocacy below Frederick.

Braddock Heights.—About 5 miles west of Frederick, on the divide between Monocacy and Catoctin Creek, is Braddock Heights. This community is a popular summer resort, practically deserted during the winter months, but having a population of about 1,200 persons during the summer months. There is a public water supply, which is secured from a covered spring about 1 mile east of town. The consumption of water is negligible during winter, but approximates 35,000 gallons daily during the summer. Cesspools and ordinary privies are used for the disposal of sewage.

AREA SURROUNDING DISTRICT OF COLUMBIA.

Goose Neck Creek.—Goose Neck Creek enters the Potomac from the south 15 miles below the mouth of the Monocacy River. This stream has a watershed of 384 square miles, with a population thereon of 41.4 persons to the square mile. It rises in the Blue Ridge Mountains and flows in a northeast direction to the Potomac. On the North Fork of Goose Neck is the town of Round Hill, with a population of 379. There is a water supply at this point derived from wells, but no sewerage system.

The only other important town in this watershed is Leesburg, Va., which has a population of 1,597. There is a public water supply at this point derived from springs and a well. The town is partly sewered, there being about half a mile of sewers which discharge into Tuscarora Creek, a small branch which enters Goose Neck a few miles above its mouth.

Seneca Creek.—About 8 miles down the Potomac below Goose Neck, Seneca Creek enters from the north. This small stream has a watershed embracing 128 square miles, with a population thereon of 54.2 persons per square mile. There are no towns of any size on the watershed.

Great Falls.—About 9 miles below the mouth of Seneca Creek are the Great Falls of the Potomac. At this point the river falls very rapidly by a series of rocky rapids. Above the rapids the river is dammed to form the intake for the Washington water supply. Below Great Falls is the District of Columbia, and surrounding this is a considerable suburban district. This suburban area will be discussed according to the various streams which drain it.

Rock Creek, Md. and D. C.—A few miles below the mouth of Little Falls Brook, just below Georgetown, Rock Creek enters the Potomac. This stream has an area of 77 square miles, with a population of 1,200 persons per square mile. The total population on the stream outside of the District of Columbia is about 3,700. The first town of importance on the stream is Rockville, Md., with a population of 1,181. Rockville has a public water supply derived from drilled wells, which furnish about 20,000 gallons per day.

A severe epidemic of typhoid fever which occurred in Rockville in the early part of 1914 was studied by officers of the Public Health Service and the Maryland State Department of Health, who found that one of the wells had become polluted by the wastes from a typhoid-fever patient. This investigation was reported in Public Health Bulletin No. 65. Rockville has recently completed a sewerage system with treatment works consisting of Imhoff tank and contact beds, effluent being discharged into Cabin John Run.

In Kensington there are two semipublic supplies, which furnish a few houses. A bond issue has been authorized for the construction of both water systems and sewerage systems. Kensington has recently completed a sewerage system discharging without treatment directly into Rock Creek.

Garrett Park, Forest Glen, Linden, Woodside, and other small communities, with the exception of Chevy Chase, which derives its supply from wells, have no public water supplies.

A considerable amount of the following information in regard to this district was obtained from a "Report upon collection and disposal of the sewage of those sections of Maryland adjacent to the District of Columbia to the sewage commission of Montgomery and Prince Georges Counties, Md., by Robert B. Morse, chief, bureau of sanitary engineering, Maryland Department of Health."

Little Falls Brook.—The first of these areas is that drained by Little Falls Brook, a small stream which enters the river just above the District line. There is a population of about 1,900 people on this stream, the majority of whom reside in the communities of Chevy Chase, Somerset, Drummond, Friendship Heights, The Hills, Bradley Hills, and Edgewood. Most of these towns are partially served by public water supplies derived from drilled wells. A con-

siderable portion of the population is served by sewers, the discharge from which finds its way into Little Falls Brook.

The following quotations from the above-mentioned report describe the condition of this stream.

> Little Falls Brook is the most badly polluted of any of the streams under consideration. * * * Its condition at certain times of the year, particularly in summer, when the stream flow is small, is almost intolerable. Both bed and banks are coated with filth and small rank organic growths caused by the entrance of sewage. At times it is no better than an open sewer, and where it passes along Rockville Road it is particularly objectionable to the public. * * * The growth of the communities affected will surely be retarded if the discharge of crude sewage into this stream is continued.

The sewage from Chevy Chase is treated in a plant which consists of a septic tank and contact beds. The other communities have no sewerage systems, the inhabitants depending upon privies and cesspools for the disposal of their wastes.

The amount of pollution entering Rock Creek at the present time is not sufficient in amount to cause a nuisance, but undoubtedly, unless conditions are changed, this stream will become badly polluted within a few years.

Anacostia Creek.—Anacostia Creek, which enters the Potomac near the southeastern corner of the District, has a drainage area of 144 square miles, on which there is a population of 509 persons per square mile. The population on Anacostia Creek, outside of the District of Columbia, was 14,773 in 1910. Only two communities on this stream have public water supplies.

Hyattsville has a public water supply derived from driven wells. The communities of Mount Rainier, Brentwood, Silver Springs, and Bladensburg have no public water supplies. Silver Spring is contemplating the construction of a water supply and a sewerage system.

Takoma Park, with a population of 1,242, is supplied with water derived from Sligo Branch and filtered through rapid sand filters. It is almost wholly served by sanitary sewers. The sewage is treated in two disposal plants—one located on Sligo Branch and the other on Takoma Park Branch. At the first point the sewage is treated in intermittent sand filters, and at the second point in septic tanks and subsurface irrigation fields. The disposal plants at Takoma Park are in very bad condition, no attention seemingly being paid to their proper operation.

The following statement from the before-mentioned report shows the condition of the Sligo Branch plant:

> At the time of the examination sewage was being permitted to discharge upon one of the beds, but instead of passing through the sand it was flowing through a hole in the center of the bed directly into an underdrain, and thence to the

stream. At another time even this pretense of treatment was not being made, for sewage was entirely shut off from the beds and was discharging directly into a stream by means of a ditch. The conditions existing at the latter time were almost indescribable.

The other plant was equally bad:

Sewage was flowing through the septic tank and also through the underdrains, and the field was apparently clogged, and, at any rate, was absolutely incapable of performing its functions; the result being that a septic liquid was discharged directly into the small stream.

A complete study of the area surrounding the District of Columbia was made, as heretofore mentioned, with the view to outlining a comprehensive plan for the design of a sanitary sewerage system for the entire district. The population of this district in 1910 was 20,523, and it is estimated that in 1950 the population will have increased to 150,000. From these figures it is clearly seen that the need of such a plan for the future construction of sewerage facilities is absolutely necessary, and it is trusted that the work will be developed along the lines pointed out in the report.

THE DISTRICT OF COLUMBIA.

The District of Columbia is by far the most important area in the whole watershed in so far as pollution of the river is concerned. The District of Columbia had a population of 331,069 in 1910. The population is rapidly increasing and it has been estimated by the United States Corps of Engineers that the District will have a population of 570,000 in 1950. A peculiar fact in regard to this city is that there is practically no manufacturing, the inhabitants for the most part being employed in the various governmental departments.

Water supply.—The District of Columbia has a public water supply derived from the Potomac River at Great Falls, where a dam has been built with its crest at an elevation of 150.5 feet above mean tide at Washington. From Great Falls it flows by gravity through a circular conduit 9 feet in diameter, for about 9 miles, to Dalecarlia reservoir; thence through a conduit of the same size for about 2 miles to Georgetown reservoir; and finally through a tunnel, about 4 miles long, to McMillan Park reservoir. At McMillan Park reservoir it is raised by means of pumps, about 21 feet to the filters. After being filtered the water flows by gravity from the filtered-water reservoir to the mains and pumping station. * * * The filtration plant is of the slow sand type and quite similar to other modern plants of the same kind. There are 29 filters each having an effective filtering area of 1 acre, and a filtered-water reservoir having a capacity of 150,000,000 gallons.

This filter plant is one of the best of its type in the world and it delivers a water that is at all times safe and potable. In times of high turbidity in the river the water entering the Georgetown reservoir is treated with aluminum sulphate, which materially reduces the load upon the filters.

The following table, from a report on the "Water Supply of the District of Columbia and Water Power at Great Falls,"[1] gives the population and water consumption from 1905 to date, as well as the estimated populations and consumptions to the year 1950.

TABLE 4.—*Water consumption.*

Fiscal year ending June 30—	Population.	Daily consumption.		Average gallons per capita daily.	Per cent of increase of maximum over average.
		Average.	Maximum.		
		Gallons.	*Gallons.*		
1905	323,000	68,700,000			
1906	326,000	67,400,000			
1907	330,000	66,900,000	80,290,000	203	20
1908	339,000	64,910,000	80,380,000	192	24
1909	343,000	61,470,000	78,930,000	179	28
1910	[1] 343,000	59,190,000	78,500,000	173	33
1911	348,000	60,380,000	78,320,000	173	29
1912	354,000	62,120,000	92,720,000	176	49
1915	378,000	[2] 66,000,000	[2] 86,000,000	[3] 173	[3] 30
1920	405,000	[2] 70,000,000	[2] 91,000,000	[3] 173	[3] 30
1930	460,000	[2] 79,000,000	[2] 103,000,000	[3] 173	[3] 30
1940	515,000	[2] 89,000,000	[2] 116,000,000	[3] 173	[3] 30
1950	570,000	[2] 99,000,000	[2] 129,000,000	[3] 173	[3] 30

[1] Since the United States census is consistently lower than the police census, the per capita consumption is based on the latter for 1909—viz, 343,000.
[2] Estimated from probable future population, assuming a per capita consumption of 173 gallons per day and a maximum consumption 30 per cent greater than the average.
[3] Assumed.

Sewerage system.—The sewerage system of the District of Columbia is undoubtedly constructed on one of the most complete and comprehensive plans of any city in the world. In 1889 sewerage conditions had become complicated on account of the sporadic growth of the city. Congress therefore made an appropriation for the employment of a board of sanitary engineers to study the entire problem. This board made its report in 1890, and the plans it proposed have been adopted and are being carried out.

The plan consists, in brief, of collecting all the sewage of the District in interceptors and conveying it to a sewage pumping station on the Anacostia River. Here it passes through a sediment or grit chamber and coarse screens and is then lifted by a series of centrifugal pumps to a receiving well. From this the sewage passes beneath the Anacostia River in two 60-inch iron-pipe inverted siphons and then through a conduit about 3 miles long to the east bank of the Potomac River. From this point it flows through two lines of 60-inch pipe to a point near the center of the channel about 800 feet from shore. The two pipes discharge about 100 feet apart in 30 feet of water.

The sewerage system is built partly on the separate, and partly on the combined, system. There are five pumps for handling the

[1] H. Doc. 1400, 62d Cong., 3d sess.

domestic sewage. These pumps have a total capacity of 350 cubic feet per second. Practically all of the sewage handled by them passes through the sediment chamber. This is 50 feet wide and 100 feet long and reduces the velocity of the entering sewage to such a point that the heavier particles are deposited. The basin is cleaned by bypassing the sewage and removing the sediment in iron buckets, which are carried on a small industrial railway to a scow into which they are emptied. At the outlet of the sediment chamber are placed the screens. There are made of $\frac{3}{4}$-inch iron rods spaced $2\frac{1}{4}$ inches apart. Eight storm-water pumps having a capacity of 100 cubic feet per second each are utilized to lift the storm matter and discharge it directly into Anacostia River. Before reaching the pumps the storm water passes through a screen chamber having screens made of $1\frac{1}{2}$-inch wrought-iron pipe on $4\frac{1}{2}$-inch centers.

In regard to the discharge into the river of domestic sewage not conveyed to the pumping station, the following information was furnished by Mr. Asa E. Phillips, superintendent of sewers:

In the territory extending from one-half mile above to a mile below Chain Bridge there are four sewer outlets which serve a total of 269 houses. Above Aqueduct Bridge and below Three Sisters Islands there are three outlets serving 265 houses. Below Aqueduct Bridge and above Rock Creek are four outlets serving 1,320 houses. It is expected to include in the annual estimates for the next fiscal year the construction of an upper Potomac River interceptor which will remove all sanitary drainage at present discharging into the river west of Rock Creek. Near the foot of New Hampshire Avenue are three outlets receiving the drainage from 45 houses. It was planned to connect these sewers with the existing intercepting system during the year 1914. Five outlets near South Capitol Street and on Ninth, Eleventh, and Twelfth Streets, SE., discharge the sewage from 162 houses into Anacostia River. Studies are now underway for the removal of this sewage from the river to the pumping station. On Benning Road a sewer serving 10 houses discharges into Anacostia River.

THE POTOMAC RIVER BELOW WASHINGTON.

The Potomac becomes a tidal stream about 3 miles above the mouth of Rock Creek. From this point down it gradually widens and changes its physical character. From Washington to the mouth there is a narrow deep channel, on both sides of which extend flats covered with shallow water at all times.

Alexandria.—Seven miles below Washington is the city of Alexandria, Va., with a population of 15,329. There is a public water supply owned by the Alexandria Water Co. and derived from Cameron Run. The water is pumped from the creeks to two reservoirs having a capacity of 16,000,000 gallons. The average daily consumption is about 1,000,000 gallons. A serious epidemic of typhoid fever occurred during the summer of 1914, the cause of which was found to be infection of the water supply. The condition was

remedied by the installation of a chlorine apparatus. Work has been going on for a year or more, which will soon result in a sufficient and safe supply from Holmes Run and Black Lick Creeks. About 60 per cent of the town is served by a sewerage system. These sewers discharge into the Potomac River at five points along the water front and into Hunting Creek at two points. The chief industrial wastes are from a large brewery and from a fertilizer plant which reduces pyrites.

Settlements near Alexandria.—Between Alexandria and Washington are a number of small settlements—Rosemont, Virginia Highlands, and Dulany—some of which are partially sewered, the discharges emptying into the river directly or by way of small creeks. The railroad yards, with 1,200 employees, have sewers to the river. Fort Myer, Va., with a normal population of about 900, derives its water supply from the Potomac River near Three Sisters. The water is filtered by rapid sand filters. About 259,000 gallons are used daily. The sewage from the fort is discharged untreated into the Potomac.

Fort Washington, Fort Hunt, Mount Vernon.—The next points of pollution are at Fort Washington, Md., and Fort Hunt, Va., located on opposite sides of the river about 5 miles below Alexandria. These forts have normal populations, respectively, of 900 and 175. Each has a water supply derived from deep wells, the average daily consumption being, respectively, 380,000 and 100,000 gallons. The sewage from each fort is discharged directly into the Potomac River. Two miles below the forts is located Mount Vernon, George Washington's home.

Indianhead.—The next point of pollution is at the United States proving ground and powder factory at Indianhead, Md. At this point the sewage of 250 persons is discharged into the Potomac. Into Mattawoman Creek runs a certain amount of water containing nitric and sulphuric acids. Large quantities of sodium sulphate are piled on the bank, and some of this is washed into the stream during rains.

Occoquan Creek and Bay.—Almost opposite Indianhead are Occoquan Bay and the mouth of Occoquan Creek. This stream has a watershed of 594 square miles, on which there is a population of 38.1 persons per square mile. Warrenton, the largest town on this watershed, with a population of 1,431, has a water supply derived from springs and a well, but no sewerage system.

There is no other town of importance on this stream, although it receives the indirect drainage of Haymarket, Manassas, Clifton, and Occoquan, Va. Manassas has voted for a bond issue for the construction of water and sewerage systems.

Cherry Hill.—The garbage-reduction plant which handles the garbage of Washington is located at Cherry Hill, Va., just below Occoquan. The only waste from this plant is leakage from the piles of solid refuse left after all the oils have been extracted. A sample of the liquid seepage from this refuse on analysis showed an enormous bacterial count, but no *B. coli*. It is therefore relatively unimportant from a sanitary standpoint.

Popes Creek.—Below Occoquan Bay the river receives the slight indirect drainage from Quantico and Widewater, small towns on the Virginia shore. There are no other points of importance until Popes Creek, Md., is reached, a distance of 55 miles below Washington. This is the terminus of the Popes Creek Branch of the Pennsylvania Railroad. Popes Creek is about the upper limit of the oyster beds in the Potomac River. The water at this point is brackish, the salt and fresh water, under ordinary conditions of stream and tide flow, meeting near Sandy Point, about 14 miles above Popes Creek.

Colonial Beach.—The next town of note is Colonial Beach, Va., about 68 miles below Washington. This is the largest town on the river between Alexandria and Point Lookout. During the months of July and August the town is visited almost daily by several hundreds of excursionists from Washington and vicinity, and the summer population is said to number 10,000 persons. The population throughout the remainder of the year is about 1,000.

During the summer of 1913 a public water supply and sewerage system was completed and the principal buildings of the town connected with them. The remaining houses are to be connected with the sewerage system as rapidly as the extensions can be made. The sewage is pumped into a septic tank divided into compartments, so that the correct storage may be had at all times of the year. The effluent from this tank discharges into Monroe Bay not far from its mouth. During the summer the amount of sewage discharged is sufficient to discolor markedly the water in the bay over the outlet. An examination in the winter showed the effluent to be only slightly turbid, with no disagreeable odor, and containing *B. coli* in 0.01 c. c. but not in 0.001 c. c. During the oyster season samples of water taken in Monroe Creek in the vicinity of the sewage-disposal plant and at the outlet of Monroe Creek on the ebb tide did not show evidences of gross pollution, while samples of water taken from the Potomac River in the general locality of Monroe Creek were not markedly different from samples several miles distant.

The public water supply of Colonial Beach is derived from an artesian well several hundred feet in depth, and many of the houses are also supplied by private artesian wells. It is worthy of note that during the period from August, 1913, to June, 1914, only two cases

of typhoid fever occurred at Colonial Beach and that both of these persons were proved to have contracted the disease during the month of August at places other than Colonial Beach. It is also of interest to observe that not a single case of typhoid fever occurred at Colonial Beach during the oyster season, notwithstanding the fact that the oysters dredged from the Potomac River in the vicinity are cheap and plentiful and form one of the principal daily articles of diet for the people in this region. It is a common sight to see persons about the wharves and neighboring streets opening oysters with pocket-knives, without stopping to wash the outside of the shells, and eating the oysters directly from the shells.

Rivers entering Potomac near Colonial Beach.—The river at Colonial Beach is about 5 miles wide. Nearly opposite this point is the Wicomico River, which is a large stream or estuary. At Rock Point, about 1½ miles above the mouth, is located Lancaster Wharf. This is a scattered community of about 200 persons. About 125 yards below the wharf is a culvert, draining a marshy area, into which the privies of a dozen houses drain. (Figs. 13 and 14.) There are oyster beds only 50 yards from this point. At the wharf is an oyster shucking and packing house. Artesian water is used for washing the oysters, which are packed in tin cans.

In Nomini Creek are the small communities of Mount Holly, Va., and Nomini Ferry, Va. This creek has many oyster layings and its shores are fairly populated. Farther down, on the Yeocomico River, is Kinsale, Va., with a population of about 250. At this point are three establishments, employing about 150 hands, who are engaged in canning tomatoes during the canning season. There is also one plant which handles fish and oysters during the winter. The water used in the process is obtained from artesian wells.

St. Clements and Bretons Bay.—About opposite the Yeocomico River are St. Clements and Bretons Bay, which are fairly large estuaries. Near the head of Bretons Bay is Leonardtown, Md., with a population of 526. The town is without public water supply or sewerage, the inhabitants depending on private wells for the former. There are two institutions in Leonardtown—St. Mary's Academy, a girls' school, and Leonard Hall, a boys' school.

Piney Point.—About 12 miles below the entrance to Bretons Bay is Piney Point, on which there is a group of houses and a hotel, which during the summer months has 50 or more guests, the total population during the summer being 100 or less persons. No sewage of consequence reaches the river from this point, at any rate during the winter months.

St. Georges Island.—A few miles below Piney Point is St. Georges Island, on which there are a few summer cottages, the winter or permanent population being very small. There is no sewage of any

moment from this place. Between St. Georges Island and Point Lookout the St. Marys River joins the Potomac River. This river is a large estuary, at the head of which is St. Marys, a small community, which includes a school for girls. Little sewage enters from this point.

Coan River.—About opposite the St. Marys River on the Virginia side is Coan River, a broad estuary, which, after running for a mile or so, divides into three branches. About 1 mile from the entrance is Lewisetta, which comprises a few houses and a large wharf, on which is a "fish factory," where herring are salted during the spring run, and during the summer months oil is extracted from large numbers of menhaden brought in by fishing steamers, the "scrap" or residue of the fish being utilized in the manufacture of fertilizers. Although sewage reaches the river from only a few houses and from fishing steamers while in port, a large amount of organic matter is found and the mud from the bottom has an offensive odor, which indicates putrefactive changes in the immediate vicinity. One of the few samples of oysters showing an excessive number of *B. coli* came from between the fish wharf and the drain from a private residence.

Below Coan River.—There are no communities between Coan River and Smith's Point, which is at the south limit of the junction of the Potomac River with the Chesapeake Bay. While there are few statistics available as to the prevalence of typhoid fever in these scattered communities along the lower river, the unanimous opinion of both the medical profession and the community at large is that the common use of artesian wells, which are found all over that district, has resulted in a very marked lessening of typhoid fever and a general improvement in the health of the communities fortunate enough to use them. The same change consequent upon the use of these wells has been noted upon the Great Wicomico and other rivers.

As is shown by the map, the drainage area on the Virginia side below Maryland Point is small, and there is no source of considerable pollution except at Colonial Beach, while on the Maryland side the population is small, and there are no communities on the river, and only such small villages as Leonardtown (532) and St. Marys on the estuaries. It is probable, therefore, that the reinfection of the lower river with *B. coli* comes from agricultural sources and the stock farms at Church Point, Pope's Creek, and Lower Cedar Point (Morgantown) rather than from human sources.

ADDITIONAL DATA ON THE SANITARY CONDITIONS OF THE POTOMAC RIVER DRAINAGE BASIN.

The data derived from direct inspection on the inhabited portions of the watershed have now been detailed. It remains to supplement

these observations with material from other sources before summarizing the extent and nature of the pollution of the stream.

Prevalence of typhoid fever.—The prevalence of typhoid fever has been shown to be unduly high by the illustrative instances given in the preceding survey. In tables 5, 6, and 7 are included the data on this matter furnished by the State health authorities of the areas concerned. After considering all available information, it is believed that the population of the upper portion of the Potomac watershed has from 500 to 600 cases of typhoid fever per 100,000 per annum. Since this population above the city of Washington amounts to about 65,000 people directly polluting the streams, it follows that the main river must carry away every year the discharges from about 375 to 400 cases of typhoid fever. These discharges may in many instances receive some preliminary treatment before reaching the streams, and it is estimated that about 16,200 people discharge some 2,600,000 gallons of sewage per diem, which has been treated in sewage-disposal plants of some description. Capt. D. D. Gaillard, Corps of Engineers, United States Army, has estimated that it takes from four to seven days for river water at Cumberland to reach Washington. (Ann. Rep. Chief of Engineers, U. S. A., 1894.) The nearest probable source of any considerable amount of pollution is at Brunswick, from which it probably takes less than 24 hours for river water to reach Washington.

TABLE 5.—*Typhoid fever in that part of Virginia on the Potomac River watershed from June 1, 1913, to June 1, 1914*—Continued.

[Data furnished by the commissioner of health of Virginia.]

Name of place.	Number of cases reported June, 1913, to June, 1914.	Number of cases reported October, 1912, to September, 1913.	Number of cases estimated October, 1912, to September, 1913.	Population, census of 1910.
Alexandria County	22	16	23	10,231
Alexandria City	1			15,329
Potomac				559
Falls Church				1,128
Augusta County	129	109	199	32,445
Staunton	4			10,604
Mount Sidney				221
New Hope	8			106
Greenville				359
Basic City	4			1,632
Waynesboro	27			1,389
Clarke County	37	35	59	7,468
Berryville	4			876
Frederick County	156	115	181	12,787
Winchester	95			5,864
Middletown				363
Stephen City	13			483
Highland County	25	14	22	5,317
Monterey	9			240
Page County	11	42	83	14,147
Luray	1			1,218
Stanley				218

TABLE 5.—*Typhoid fever in that part of Virginia on the Potomac River watershed from June 1, 1913, to June 1, 1914*—Continued.

Name of place.	Number of cases reported June, 1913, to June, 1914.	Number of cases reported October, 1912, to September, 1913.	Number of cases estimated October, 1912, to September, 1913.	Population, census of 1910.
Rockingham County	87	74	114	34,903
Harrisonburg	12			4,879
Bridgewater	3			859
Dayton	2			516
Mount Crawford				228
Singer Glen	6			110
Broadway	5			416
Timberville	4			240
Elkton	7			873
Shendon				456
Shenandoah County	136	124	187	20,942
Mount Jackson	8			479
Strasburg	14			762
Woodstock	14			473
New Market	13			638
Edinburg	12			574
Warren County	38	16	30	8,589
Front Royal	27			1,133
Loudoun County	76	44	82	21,167
Hillsboro	3			138
Round Hill	7			379
Waterford	2			331
Leesburg	19			1,597
Lovettsville	11			192
Middleburg				263
Hamilton	6			315
Purcellville	1			388
Westmoreland County	60	46	93	9,313
Colonial Beach	5			721
Prince William County	36	29	52	12,026
Dumfries				158
Haymarket				162
Manassas	12			1,217
Occoquan				246
Fauquier County	119	79	146	22,526
Warrenton	22			1,427
Remington	10			251
Upperville				296
Fairfax County	27	25	49	20,536
Clifton				204
Herndon	1			802
Wiehle				70
Fairfax	12			413
Vienna	3			578

TABLE 6.—*Typhoid fever on the Potomac River watershed of Maryland.*

[From information furnished by the State health officer of Maryland.]

Place.	Number of cases reported during—								Population, 1910 census.
	1907	1908	1909	1910	1911	1912	1913	June 1, 1913, to June 1, 1914.	
Adamstown	2	3	7	1	2	0	0		256
Araby	4	0	1	2	1	0	1		25
Ardwick	[1]	1	[1]	[1]	[1]	[1]	[1]		21
Allegany Hospital						1	[1]		150
Barton	2	[1]	3	[1]	[1]	[1]	1		1,287
Bell Alton	[1]		10		1		[1]		250
Bethesda	4	0				2	[1]		75
Barnesville	1		1	1	5	[1]	[1]		125
Beaver Creek				1		1	[1]		72
Bigpool		4	2	2	6	1			125
Boonsboro	1	1						1	759

[1] No report.

TABLE 6.—*Typhoid fever on the Potomac River watershed of Maryland*—Contd.

Place.	Number of cases reported during—								Population, 1910 census.
	1907	1908	1909	1910	1911	1912	1913	June 1, 1913, to June 1, 1914.	
Boyds	2	1	1	1			(1)		250
Bradelock						1	(1)		
Big Spring					2		(1)		50
Berwyn			4	2	1				150
Brentwood		2	2	1	1	2	(1)		200
Bakersville			1				(1)		27
Berry						1	(1)		40
Brunswick	28	35	13	30	16	14	3	64	3,721
Buckeyestown	2	12	12	2	3	2	0		85
Bryantown			9	3	18				120
Burdett	2						(1)		23
Burkettsville		8	2	0	0	1	2	3	228
Borden Shaft			1				(1)		39
Borden Mine			1				(1)		
Camp Springs			1				(1)		60
Capital Heights		1	0	2	11	3	2		275
Carlos			1			1	(1)		500
Clear Spring		1	25	5	11	1	4	10	521
Clarksburg	1	0		3			(1)		150
Clinton	1		5	3			(1)		100
Compton		2					(1)		75
Comas	2				1	1	(1)		75
Chewsville	1	1	1	1		1	(1)		152
Chevy Chase			1	1	2		(1)		
Corriganville			1	0	1	0	1		100
Cumberland	121	66	118	560	320	196	160	299	21,839
South Cumberland					6	1	(1)		
"Near Cumberland"					2		(1)		
Dam No. 4					1	0	(1)		
Downsville	1			1	1	6	(1)		152
Dargan			1				(1)		60
Derwood		1	2	2	0	0	(1)		72
Doubs		1					(1)		37
Dickerson			4	1		8	(1)		125
District No. 10			1				(1)		
Eckhart			6	2	0	2	(1)		1,600
Eckhart Mines			1	0	4	3	2		
Ellerslie	1	0	0	0	0	0	(1)		600
Etchinson	1	0	0	0	0	0	(1)		58
Eakles Cross Roads			4	0	0	0	0		
Eakles Mills					1	1	0		120
Emmitsburg	0	0	1				(1)	1	1,054
Fairview		1	0	0	0	0	(1)		97
Fairplay			1	1	6	0	(1)		
Frederick	37	26	50	52	62	49	2	22	1,441
Forest Glen		2	0	0	0	0	(1)		70
Forestville		2	0	4	2	2	(1)		100
Flint Hill	2	0	0	0	0	0	(1)		
Frostburg	2	24	19	19	47	21	2	5	6,028
Flintstone	0	0	2	0	0	0	(1)		250
"Near Frederick"					4	0	(1)		
Franklin	0	0	0	0	0	17	(1)		
Funkstown			1	0	0	0	4	0	568
Gapland	0	0				1	1		100
Gaithersburg		2	1	2	0	0	(1)	0	625
Germantown	1		4	0	1	0	(1)		250
Gilmore	3	0	0	1	1	0	(1)		125
Great Falls	2	0	0	0	0	0	(1)		93
Hagerstown	35	46	44	46	41	36	19	97	16,507
Hancock	8	5	9	3	1	5	1	50	893
Hunting Hill		4					(1)		35
Hyattsville	1	3	3	2	0	3	0	4	1,917
Ijamsville	2	0	1	0	1	2	0		70
Johnsville	1	0	0	0	0	0	(1)		196
Issue	0	0	1	0	0	0	(1)		57
Knoxville	3	0	0	1	0	4	(1)		363
Kensington	0	1	1	0	2	0	(1)	0	689
Keedysville	1	1	0	1	18	10	1	7	367
Kearney	1	0	0	0	0	0	(1)		
La Plata	1	0	20	1	2	8	3	0	269
Lonaconing	6	14	13	46	21	9	4	18	1,553
Leitersburg	0	1	2	2	1	0	(1)		340
Libertytown	3	0	2	0	0	1	(1)		589
Linden	2	0	0	0	0	0	(1)		57

[1] No report.

TABLE 6.—*Typhoid fever on the Potomac River watershed of Maryland*—Contd.

Place.	Number of cases reported during—								Population, 1910 census.
	1907	1908	1909	1910	1911	1912	1913	June 1, 1913, to June 1, 1914.	
Mason Spring	1	0	1	0	0	0	([1])	....	55
Monrovia	0	1	0	3	1	1	([1])	....	275
Midland	1	....	....	....	2	1	([1])	4	1,173
Middletown	1	0	5	3	6	9	1	9	692
Montrose	1	1	....	....	....	....	([1])	....	30
Mount Pleasant	5	0	0	0	2	4	([1])	....	125
Mount Ephraim	0	0	1	0	0	0	([1])	....	....
Mount Airy	0	0	0	0	1	0	([1])	8	622
Mount Savage	2	0	0	1	3	3	4	....	2,000
Mount Rainier	0	3	1	0	0	0	([1])	1	1,242
Myersville	0	0	3	0	6	5	([1])	....	475
New Market	3	3	4	8	6	2	([1])	2	320
New Windsor	1	0	0	0	0	0	2	1	446
New London	2	0	0	0	0	0	0	....	100
Norbeck	1	6	0	3	....	....	....	....	50
North Branch	1	0	0	....	....	....	....	....	....
Newport	0	0	7	2	2	1	([1])	....	50
Newburg	0	0	2	0	1	0	([1])	....	87
National	0	0	0	4	0	0	([1])	....	....
New London, near	....	....	....	....	1	0	([1])	....	100
Oxen Hill	1	0	3	0	0	0	([1])	....	65
Oakdale	0	0	0	2	0	0	([1])	....	53
Olney	0	0	2	0	0	0	([1])	....	150
Potomac	3	7	0	0	0	0	([1])	....	127
Park Mills	1	0	0	0	0	0	([1])	....	80
Paradise	....	....	2	....	....	....	([1])	....	....
Pearl	3	....	....	....	....	2	([1])	....	52
Pomonkey	4	1	2	0	1	0	([1])	....	200
Pomfret	....	....	....	....	....	4	([1])	....	60
Poolsville	1	0	1	0	0	5	3	0	175
Pondsville	0	1	0	0	0	1	([1])	....	100
Pisgah	0	0	3	....	1	0	([1])	....	150
Pope Creek	0	0	1	0	0	0	([1])	....	67
Rockville	19	11	3	16	9	5	([1])	35	1,181
Rock Bridge	1	0	0	0	0	0	([1])	....	....
Rock Point	0	0	3	0	0	0	([1])	....	476
Rocky Ridge	....	....	....	....	1	1	([1])	....	125
Rohpersville	0	0	0	2	1	2	([1])	....	200
Riverdale	0	3	2	....	1	1	([1])	....	125
Rosecroft	....	....	....	1	....	....	....	....	50
Ringgold	....	....	....	....	1	0	([1])	....	114
Smithsburg	2	0	2	2	10	4	10	7	481
Sabillasville	1	0	0	0	0	0	2	....	180
Silver Spring	0	3	0	1	0	0	([1])	....	200
Silver Hill	0	7	0	0	0	0	([1])	....	110
Sellman	0	0	2	2	2	2	([1])	....	100
Sharpsburg	0	0	2	0	5	0	([1])	8	961
Sandy Spring	0	0	1	0	4	3	([1])	....	135
Sandy Hook	0	0	0	0	0	1	([1])	....	....
"T. B."	1	0	2	1	2	0	([1])	....	65
Tippett	....	1	....	....	....	....	([1])	....	20
Trego	....	....	....	....	0	1	1	....	75
Travillah	2	0	0	1	0	0	([1])	....	50
Thurston	1	....	....	....	....	....	([1])	....	....
Takoma Park	....	0	1	0	0	2	([1])	8	1,242
Urbanna	2	0	0	0	4	1	([1])	....	219
Utica Mills	1	1	0	0	0	0	([1])	....	60
Security	....	....	....	0	6	0	([1])	....	....
Wheaton	1	0	2	....	....	....	([1])	....	71
Waldorf	....	1	0	5	26	1	([1])	....	250
Walkersville	3	0	0	1	4	0	([1])	4	582
Westernport	0	1	0	0	0	15	44	120	2,702
White Plains	1	1	....	....	1	0	([1])	....	100
Woodsboro	1	....	....	6	4	1	1	3	362
Woodville	1	0	....	....	....	....	([1])	....	48
Weverton	....	....	....	1	3	10	....	....	136
Wayside	....	....	1	....	....	....	....	....	200
Williamsport	....	6	13	12	3		([1])	7	1,571
Western Maryland Hospital	....	....	....	....	....	11	....	....	....
Westminster	....	....	....	....	....	....	....	7	3,295

[1] No report.

TABLE 6.—*Typhoid fever on the Potomac River watershed of Maryland*—Contd.

Place.	June 1, 1913, to June 1, 1914.	Population according to census 1910.
Union Bridge	10	804
Taneytown	0	824
Kitzmillerville	3	865
Laytonsville	0	133
Point of Rocks	2	476
Thurmont	2	903
Bloomington	10	372
Garrett Park	0	185
Glen Echo	0	203
Somerset	0	173
Damascus	0	170
Bladensburg	0	460
Piscataway	0	73
Leonardtown	0	526
Charles	0	....

NOTE.—Dr. Fulton, State health officer of Maryland, wrote with reference to the above statistics: "I may say in general about these reports that they tend to show in many cases larger numbers of persons than are actually sick at a given town. This happens because the reports do not enable us to distinguish between citizens of the towns and persons who receive their mail at the town."

TABLE 7.—*Typhoid fever on the Potomac River watershed of West Virginia.*

[From data furnished by the secretary of the State Board of Health of West Virginia.—Cases and deaths reported during the period June 1, 1913, to June 1, 1914.]

Name of community.	Population according to census of 1910.	Cases reported.	Deaths.
Bayard	417	0	0
Berkeley Springs	864	4	0
Capon Bridge	213	(1)	....
Charles Town	2,662	(1)	....
Elk Garden	438	5	0
Franklin	200	1	0
Harpers Ferry	766	0	0
Hedgesville	328	2	0
Keyser	3,705	(1)	....
Martinsburg	10,698	40	9
Moorefield	646	10	0
Paw Paw	725	(1)	....
Piedmont	2,054	(1)	....
Romney	1,112	2	0
Springfield	135	(1)	....
Shepherdstown	1,070	0	0
Wardensville	123	(1)	....
Watson (Capon Springs post-office)	11	(1)	....

[1] No report.

The above report covers only a few of the urban communities. As the reporting of disease has just been inaugurated in the State, it is natural that as yet the report even for these towns is very incomplete. This is perhaps less true of Martinsburg and Moorefield than of the other towns.

Areas and populations on the watershed.—The areas and populations of the watershed may be found in Table 8.

TABLE 8.—*Tabulation of areas and populations in watershed of Potomac River and its tributaries.*

Stream.	Area of watershed in square miles.	Total population.			Urban population.		
		1910	1900	1890	1910	1900	1890
Savage River	115	2,560	2,551	2,131	....	....	....
Georges Creek	78	12,747	11,216	7,045	8,754	7,455	3,804
Patterson Creek	278	6,786	5,482	6,346	....	....	....
Wills Creek	241	11,972	11,375	9,852	1,357	1,400	1,239
Evitts Creek	113	4,529	4,450	4,205	....	....	....
Direct drainage to South Branch of Potomac River	517	50,048	40,551	32,023	33,084	25,293	17,438
Total for North Branch	1,342	88,642	75,625	61,602	43,195	34,148	22,481
South Branch of Potomac River	1,558	23,003	23,243	20,518	2,333	1,634	946
Town Creek	150	7,059	6,806	6,248	....	....	....
Little Capon Creek	114	1,790	1,937	1,920	....	....	....
Sideling Creek	95	3,611	3,547	2,360	....	....	....
Great Cacapon Creek	609	10,050	9,990	9,520	347	170	106
Great Tonoloway Creek	92	2,146	2,190	2,229	....	....	....
Sleepy Creek	142	3,972	3,814	3,790	....	....	....
Licking Creek	187	6,742	6,759	6,742	579	576	594
Back Creek	279	8,616	8,963	8,395	328	342	448
Conococheague Creek	582	45,694	42,251	40,586	15,376	11,528	10,617
Opequon Creek	346	28,389	24,998	23,960	16,562	12,725	12,422
Antietam Creek	289	42,124	36,939	30,933	25,881	21,134	15,602
Direct drainage to Potomac River between South Branch and Shenandoah River	503	31,253	30,343	28,053	7,370	7,354	6,500
Total for Potomac River above Shenandoah River	6,288	303,091	277,405	246,856	111,971	89,611	69,716
Shenandoah River	3,058	133,699	128,277	121,135	35,726	27,624	21,414
Catoctin Creek	122	7,126	7,630	7,676	920	894	667
Monocacy River	962	74,903	71,035	73,980	25,471	18,327	19,228
Goose Creek	384	15,899	16,240	16,607	3,238	2,867	2,693
Seneca Creek	128	7,866	7,640	6,501	928	843	....
Rock Creek	77	92,446	78,200	64,522	89,137	74,958	61,422
Anacostia Creek	144	73,325	60,621	50,750	65,579	53,558	44,430
Direct drainage to Potomac River between Harpers Ferry and Alexandria	680	242,265	206,588	175,186	206,197	173,429	143,959
Total for Potomac River above Alexandria, Va.	11,843	950,620	853,636	763,213	539,167	442,111	363,529
Occoquan River	594	22,646	21,787	19,988	3,256	2,741	2,173
Direct drainage to Potomac River between Alexandria and mouth	1,558	64,836	64,255	56,433	3,107	2,433	1,429
Total Potomac River	13,995	1,038,102	939,678	839,634	545,530	447,285	367,131

TABLE 8.—*Tabulation of areas and populations in watershed of Potomac River and its tributaries*—Continued.

Stream.	Rural population.			Population per square mile.					
				Total.			Rural.		
	1910	1900	1890	1910	1900	1890	1910	1900	1890
Savage River	2,560	2,551	2,131	22.2	22.2	18.5	22.2	22.2	18.5
Georges Creek	3,993	3,761	3,241	163.4	143.8	90.4	51.2	48.2	41.6
Patterson Creek	6,786	5,482	6,346	24.4	19.7	22.8	24.4	19.7	22.8
Wills Creek	10,615	9,975	8,613	49.7	47.2	40.9	44.1	41.4	35.7
Evitts Creek	4,529	4,450	4,205	40.1	39.44	37.2	40.1	39.4	37.2
Direct drainage to South Branch of Potomac River	16,964	15,258	14,585	96.8	78.4	61.9	32.8	29.5	28.2
Total for North Branch	45,447	41,447	39,121	66.1	56.4	45.9	33.9	30.9	29.2
South Branch of Potomac River	20,670	21,609	19,572	14.8	14.9	13.2	13.3	13.9	12.6
Town Creek	7,059	6,806	6,248	47.1	45.4	41.7	47.1	45.4	41.7
Little Capon Creek	1,790	1,937	1,920	15.7	17.0	16.8	15.7	17.0	16.8
Sideling Creek	3,611	3,547	2,360	38.0	37.3	24.8	38.0	37.3	24.8
Great Cacapon Creek	9,703	9,820	9,414	16.5	16.4	15.6	15.9	16.1	15.5
Great Tonoloway Creek	2,146	2,190	2,229	23.3	23.8	24.2	23.3	23.8	24.2
Sleepy Creek	3,972	3,814	3,790	26.7	26.9	26.7	26.7	26.9	26.7
Licking Creek	6,163	6,183	6,148	36.1	36.1	36.0	33.0	33.1	32.9
Back Creek	8,288	8,621	7,947	30.9	32.1	30.1	29.8	30.9	28.5
Conococheague Creek	30,318	30,723	29,969	77.5	72.6	69.7	52.1	52.8	51.5
Opequon Creek	11,827	12,273	11,538	82.0	72.2	69.2	34.1	35.5	33.3
Antietam Creek	16,243	15,805	15,331	145.8	127.8	107.0	56.2	54.7	53.1
Direct drainage to Potomac River between South Branch and Shenandoah River	23,883	22,989	21,553	62.1	60.3	55.8	47.5	45.7	42.8
Total for Potomac River above Shenandoah River	191,120	187,794	177,140	48.2	44.1	39.3	29.6	29.9	28.2
Shenandoah River	97,973	100,653	99,721	43.7	41.9	39.6	32.0	32.9	32.6
Catoctin Creek	6,206	6,736	7,009	58.4	62.5	63.7	50.9	55.2	57.4
Monocacy River	49,432	52,708	54,752	77.9	74.9	76.9	51.4	54.8	56.9
Goose Creek	12,661	13,373	13,914	41.4	42.3	43.2	33.0	34.8	36.2
Seneca Creek	6,938	6,797	6,501	54.2	53.1	50.8	61.4	59.7	50.8
Rock Creek	3,309	3,242	3,100	1,200.0	1,015.0	838.0	43.0	42.1	40.3
Anacostia Creek	7,746	7,063	6,320	509.0	421.0	326.0	53.8	40.1	43.9
Direct drainage to Potomac River between Harpers Ferry and Alexandria	36,068	33,159	31,227	356.0	304.0	258.0	53.0	49.0	46.0
Total for Potomac River above Alexandria, Va.	411,453	411,525	399,684	80.2	72.0	64.4	34.7	34.7	33.7
Occoquan River	19,390	19,046	17,815	38.1	36.7	33.7	32.6	32.1	30.0
Direct drainage to Potomac River between Alexandria and mouth	61,729	61,822	55,004	41.6	41.2	36.2	39.6	39.7	35.3
Total Potomac River	492,572	492,393	472,503	72.2	67.1	60.0	35.2	35.2	33.8

A study of Table 8 indicates that there is a general movement from the rural communities and small towns to the large towns and cities. For the past 10 years this has been true to a very great degree. The rural population increased from 1900 to 1910 only 0.04 of 1 per cent, while the urban population increased 21.9 per cent. As the population of a town increases the questions of water supply and waste disposal become more complicated, and after a time it is necessary as a health measure to install a public water supply. Following this, the question of sewers becomes more important, and their construction follows as a matter of course. Thus the concentration of the population in large towns results in a constantly increasing amount of pollution of the river.

Public water supplies.—The towns on the watershed are remarkably well served by public water supplies, the majority of which are

derived either from small feeders to the Potomac and its main branches or from springs flowing into these. The Potomac River proper serves as a source of supply only for the city of Washington. There are 63 other communities supplied with water, which had in 1910 a total population of 516,580. This is 94.7 per cent of the total urban population. A total population of 396,285 is supplied with water, either filtered or treated with chlorine, or both. Approximately 85,000,000 gallons of water are used daily by the above towns, of which 72,000,000 gallons are filtered or chemically treated.

Following is a tabulation of the public water supplies:

TABLE 9.—*Public water supplies in Potomac River watershed.*

Town.	Population.	Source.	Consumption.	Treatment.
			Gals. per diem.	
Bloomington, Md	372	Piedmont supply, Savage River.	20,000	
Luke, Md	510	Condenser Waterwork, Pulp & Paper Co.	20,000	
Piedmont, W. Va	2,054	Savage River	510,000	
Westernport, Md	2,702			
Frostburg, Md	6,028	Springs	350,000	
Midland, Md	1,173	do	85,000	
Lonaconing, Md	1,553	Koontz Run and Jackson River.	150,000	
Keyser, W. Va	3,705	Springs	350,000	
Hyndman, Pa	1,164	do	40,000	
Cumberland, Md	21,839	Evitts Creek	8,500,000	Rapid sand filters and hypochlorite.
Franklin, W. Va	200	South Branch Potomac	20,000	
Moorefield, W. Va	646	Moorefield River and spring.	15,000	
Romney, W. Va	1,112	Springs	10,000	
Berkeley Springs, W. Va	864	Warm Spring	72,000	
McConnelsburg, Pa	579	Springs	20,000	
Mont Alto Sanitorium	1,250	Little Antietam Creek	100,000	Hypochlorite.
Chambersburg, Pa	11,800	Springs	1,750,000	
Greencastle, Pa	1,919	do	125,000	
Mercersburg, Pa	1,410	Buck Run	10,000	
Winchester, Va	5,864	Rouse Spring	1,000,000	Chlorine gas.
Martinsburg, W. Va	10,698	Spring	1,430,000	Hypochlorite.
Waynesboro, Pa	7,199	Mountain stream	1,300,000	
Perrysville, Pa	312	do	20,000	
Hagerstown, Md	16,507	Mountain stream and Antietam Creek.	2,500,000	Filtration and hypochlorite.
Basic, Va	1,623	Spring	200,000	
Waynesboro, Va	1,389	do	150,000	
Staunton, Va	10,604	Springs	1,300,000	
Bridgewater, Va	859	do	[1] 10,000	
Harrisonburg, Va	4,879	Dry River	600,000	
Elkton, Va	873	Elkton Lithia Spring	90,000	
Shenandoah, Va	1,431	Shenandoah River	150,000	
Luray, Va	1,218	Mountain streams	250,000	
Mount Jackson, Va	479	Springs	40,000	
Edinburg, Va	574	do	15,000	
Woodstock, Va	1,314	do	100,000	
Strasburg, Va	769	do	100,000	
Riverton, Va	670	Front Royal system	100,000	Rapid sand filters and hypochlorite.
Front Royal, Va	1,133	Happy Run	400,000	
Berryville, Va	876	Springs	80,000	
Charles Town, W. Va	2,662	Spring and creek	400,000	
Brunswick, Md	3,721	Wells	60,000	
Middletown, Md	692	Spring	60,000	
Burkittsville, Md	228	do	5,000	
Gettysburg, Pa	4,030	Marsh Run	400,000	Do.
Maryland Tuberculosis Sanitarium.	550	Spring and wells	50,000	
Emmitsburg, Md	1,054	Mountain stream	150,000	
Littlestown, Pa	1,347	Wells	95,000	
Tarrytown, Md	842	do	40,000	

[1] Near.

TABLE 9.—*Public water supplies in Potomac River watershed*—Continued.

Town.	Population.	Source.	Consumption.	Treatment.
			Gals. per diem.	
Westminster, Md	3,295	Spring and wells	280,000	
New Windsor, Md	446	Springs	40,000	
Union Bridge, Md	804	Wells	140,000	
Thurmont, Md	903	High Run	90,000	
Walkersville, Md	582	Spring	45,000	
Frederick, Md	10,411	Tuscarora and Fishing Creeks.	2,500,000	
Braddock Heights	[1] 1,200	Spring	35,000	
Rockville, Md	1,181	Wells	20,000	Hypochlorite.
Tacoma Park	1,242	Stream	40,000	Rapid sand filters.
Hyattsville, Md	1,917	Wells	150,000	
Round Hill, Va	379	do	30,000	
Leesburg, Va	1,597	Spring and well	140,000	
Warrenton, Va	1,427	do	130,000	
Alexandria, Va	15,329	Holmes Run	1,000,000	
Washington	331,069	Potomac River	5,700,000	Slow sand filters.
Colonial Beach, Va	721	Wells	50,000	

[1] Summer.

Sewerage systems.—In the matter of sewers the towns are not nearly so progressive, there being several large cities having no sewerage systems. There is a total of about 394,000 people served by sewers and this number discharges in the neighborhood of 63,000,000 gallons of sewage daily into the Potomac and its tributaries. The sewage of 16,200 people (about 2,600,000 gallons) is treated in sewage-disposal plants. Public sentiment is slowly reaching a point where the discharge into a stream of such quantities of crude sewage as will create a nuisance will be prohibited, and the installation of some form of treatment will be required. Table 10 contains information regarding sewerage systems on the watershed.

TABLE 10.—*Sewerage systems in Potomac River watershed.*

Town.	Population 1910.	Population served by sewers.	Discharges into—	Treatment.
Piedmont, W. Va	2,054	2,054	North Branch Potomac	
Luke, Md	2,702	2,702	North Branch Potomac and Georges Creek.	
Frostburg, Md	6,028	3,000	Georges Creek	
Lonaconing, Md	1,553	1,553	do	
Keyser, W. Va	3,705	3,705	New Creek and North Branch Potomac.	
Hyndman, Pa	1,164	300	Wills Creek	
Allegheny Grove		100	Braddocks Run	
Cumberland, Md	21,839	20,000	Wills Creek, Potomac River, and canal.	
Franklin, W. Va	200	100	South Branch Potomac	
Moorefield, W. Va	646	200	Moorefield River	
Romney, W. Va	1,112	500	South Branch Potomac	
Berkley Springs, W. Va	864	1,000	Warm Spring Run	
South Mountain Sanatorium	1,250	1,250	Conococheague Creek	Septic tank.
Chambersburg, Pa	11,800	3,000	do	Sprinkling filters, sand filters, Imhoff tanks, settling tanks.
Mercersburg, Pa	1,410	800	do	Screens; sand filters.
Winchester, Va	5,864	5,864	Opequan Creek	
Martinsburg, W. Va	10,698	500	Tuscarora Creek	
Hagerstown, Md	16,507	2,000	Antietam Creek	

TABLE 10.—*Sewerage systems in Potomac River watershed*—Continued.

Town.	Population 1910.	Population served by sewers.	Discharges into—	Treatment.
Basic Va	1,623	800	Shenandoah River	
Waynesboro, Va	1,389	1,000	do	
Staunton, Va	10,604	6,000	do	
Bridgewater, Va	859	100	do	
Harrisonburg, Va	4,879	4,879	do	
Elkton, Va	873	100	do	
Luray, Va	1,218	500	do	
Mount Jackson, Va	479	400	do	
Edinburg, Va	574	100	do	
Strasburg, Va	769	150	do	
Front Royal, Va	1,133	400	do	
Brunswick, Md	3,721	1,000	Potomac River	
Middletown, Md	692	100	Catoctin Creek, Md	
Gettysburg, Pa	4,030	4,030	Monocacy River	Septic tank and hypochlorite.
Maryland Tuberculosis Sanitarium.	550	550	Underground tiles	Septic tank and underground filters.
Emmitsburg, Md	1,054	1,500	Monocacy River (Toms Creek).	
Tarrytown, Md	842	20	Monocacy River	
Frederick, Md	10,411	4,000	do	
Leesburg, Va	1,597	500	Tuscarora Creek	
Environs of Washington	17,020	5,000	Rock Creek, Little Falls Brook, and Antacostia River.	None.
Takoma Park	1,242	1,000	Anacostia Creek	Sand beds and irrigation.
Hyattsville, Md	1,917	1,500	do	
Washington, D. C	331,069	300,000	Potomac River	Screens and short period of sedimentation.
Alexandria, Va	15,329	9,000	do	
Colonial Beach, Va	721	500	Potomac River—Monroe Bay.	Septic tank.
Alexandria environs	4,000	2,000	Potomac River	

Trade wastes in Potomac River watershed.—A considerable amount of liquid trade wastes enters the streams and in many cases renders them offensive and disagreeable to the eye as well as unfit for drinking purposes. The most important wastes are from coal mines, tanneries, dye works, and paper mills. The acid-iron waters which are derived from the coal mines in the upper part of the watershed undoubtedly constitute the greatest source of pollution and probably have a greater influence on the character of the stream than any other wastes. It is impossible to estimate the amount of this waste. The next important waste is that from the numerous tanneries which are scattered throughout the watershed above Washington. The total amount of such waste is about 600,000 gallons per day. This in many cases renders the stream offensive, kills the fish, and from an esthetic standpoint is the most important waste in the watershed. Realizing that there is no known efficient method for the disposal of this waste, the Public Health Service has undertaken an investigation with a view to evolving, if possible, a cheap and efficient method of treatment. At all the tanneries visited during the sanitary survey there was manifested by the operators a wish for a solution of this problem.

The wastes from dye works, while of a disagreeable appearance, do not long persist in the streams and are probably of small sanitary significance. Paper-mill wastes from the sulphite mill at Luke have a striking effect on the river and materially change its character. This action is lessened, however, by mixture with the acid-iron wastes of Georges Creek, the result of which is descussed more fully at another point. Table 11 shows the kind and amount of the principal trade wastes in the upper watershed.

TABLE 11.—*Trade wastes in Potomac River watershed.*

Town.	Kind.	Amount.	Into—
		Gallons per day.	
Gormania, W. Va	Tannery	10,000	North Branch Potomac.
Luke, Md	Papel mill, sulphide	23,000,000	Do.
Keyser, W. Va	Woolen mill		Do.
Midland, Md	Mine water		Georges Creek.
Claysville, Md	do		Braddocks Run.
Allegheny Grove	Distillery	150,000	Wills Creek.
Cumberland, Md	Tannery	10,000	Do.
Do	Ammoniacal liquors	200	Do.
Do	Dye waste	50,000	Chesapeake & Ohio Canal.
Petersburg, W. Va	Tannery	10,000	Lunice Creek.
Moorefield, W. Va	do	10,000	Moorefield River.
Pawpaw, W. Va	do	50,000	Potomac River.
Chambersburg, Pa	Dye waste	5,000	Conococheague Creek.
Do	Paper mill		Do.
Do	Creamery		Do.
Mercersburg, Pa	Tannery	100,000	Do.
Williamsport, Md	do	60,000	Do.
Martinsburg, W. Va	Knitting mills	35,000	Tuscarora Creek.
Hagerstown, Md	Bleach and soda ash	70,000	Antietam Creek.
Do	Spirit dyes	10,000	Do.
Do	Paper mill, soda	100,000	Do.
Do	Wash water from brewery.		Do.
Basic City, Va	Tan extract works		Shenandoah River.
Harrisonburg, Va	Tannery	100,000	Into town sewers.
Elkton, Va	do	60,000	Shenandoah River.
Luray, Va	do	150,000	Do.
Burkittsville, Md	Distillery	6,000	Catoctin Creek.
Frederick, Md	Dye wastes	10,000	Monocacy River.

SUMMARY ON POLLUTION OF THE POTOMAC RIVER, AS SHOWN BY A SANITARY SURVEY.

It has been shown that the waters of the upper river are continuously polluted to an extent which renders them unsuitable as supplies for domestic use, without suitable preliminary treatment, and that this pollution, on account of the undue prevalence of typhoid fever on the watershed, is of a dangerous character. The pollution of the lower river has been shown to come preponderatingly from the cities of Washington and Alexandria, that introduced below these points being practically negligible from a sanitary standpoint. A small amount of bacteriological work on the upper river has been reported confirming the estimate of the pollution obtained from the sanitary survey, but the great bulk of the laboratory work was concentrated upon the lower river, where it was necessary in order to estimate

accurately the effect of the very important and interesting process of purification naturally operating in that area. The laboratory findings concerning pollution will next be considered.

POLLUTION AS SHOWN BY LABORATORY METHODS.

SAMPLING STATIONS AND CROSS SECTIONS.

These were selected after due consideration of the available data regarding the sewer outlets, stream flow and direction, location of flats and oyster beds, and other pertinent matters. At Great Falls, where the upper river terminates and the lower begins, daily samples are taken by the Washington filtration plant, and the data thus obtained were available. The next point at which samples were obtained was at Three Sisters Islands, in the river opposite the upper portion of the city of Washington. These two stations represent the waters of the upper river, uncontaminated, at least grossly, by wastes from the city. At the stations at D Street, red buoy, and the channel station, all located in the immediate vicinty of Washington, there are added the waters from the Chesapeake & Ohio Canal and Rock Creek, a small but polluted stream entering the river at Washington. The water of the Washington Channel contains at flood tide contamination from the sewer outlets of the city, and samples were taken here.

The first cross section was established on a line from Giesboro Point, Md., 5 miles below Three Sisters, to the Virginia Flats. On the ebb tide it represents the waters of the Potomac as constituted at Three Sisters, and in addition those of the Eastern Branch or Anacostia River and of the Washington Channel. At flood tide sewage from the sewer outlets of the city, 1 mile below, is added.

The Fort Foote cross section is 5½ miles below Giesboro Point. The river has now received the sewage of the cities of Washington and Alexandria, the latter being 1½ miles distant. The river bed is narrow at this point. The river below this becomes broader, receives Broad Creek, and, 4 miles below, at Fort Washington and Fort Hunt, again becomes narrow and deep, receiving sewage from these Army posts. Becoming wider in front of Mount Vernon, it receives Little Hunting and Piscataway Creeks. At Marshall Hall, 5 miles below Fort Washington, it is again constricted.

After receiving the waters of Dogue Creek, it again becomes narrow at Whitestone Point, 5½ miles below Fort Washington. Here there is a narrow and deep channel near the Virginia shore and much deposit on the Maryland Flats. Having received the outflow from Gunston Cove, the river becomes broader. and 6 miles below Whitestone Point is 1¼ miles wide between Indianhead and Sycamore

Point. Just below the cross section at this point the river receives from the Virginia side the Occoquan, or historic Bull Run, which drains a considerable area of populated country. In addition to pollution, this stream brings down after rains or snows a suspension of very red clays, the influence of which may be traced for many miles down the river.

The stretch of 24 miles from Indianhead to Maryland Point, or the "wide water," varies from $1\frac{3}{4}$ miles to 4 miles in width. In addition to the pollution from Occoquan, this section receives that from the Naval Proving Station at Indianhead; the powder factory on Mattawoman Creek, on the Maryland side; the garbage-disposal plant of the city of Washington at Cherry Hill; and several small unsewered communities on the Virginia side. In addition to these sources of pollution this reach of the river presents other conditions found to be of utmost importance.

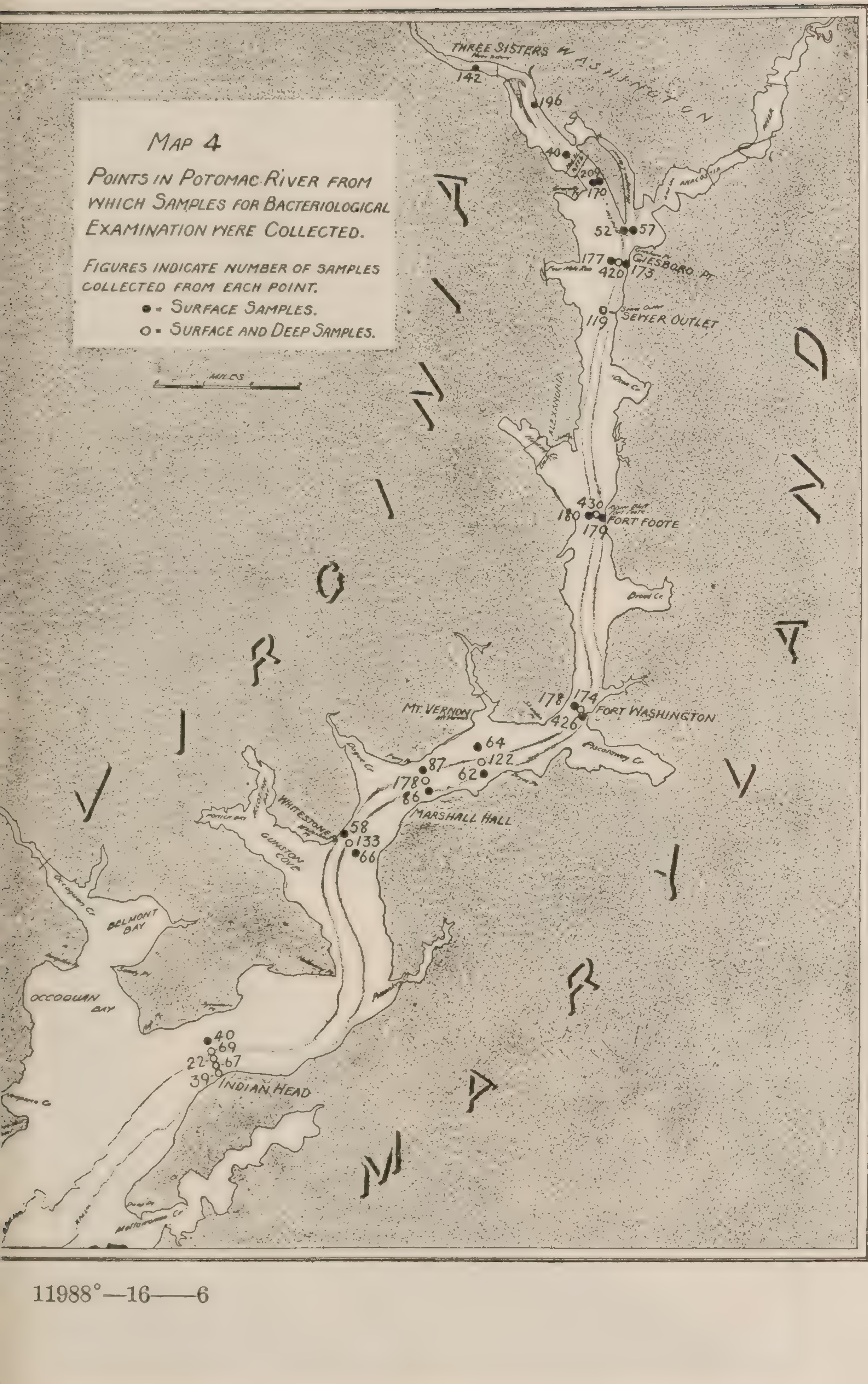
In this region first occurs the meeting of the land and sea waters with the changes consequent upon it. The wide bed and slower current, the meeting of the tide and current with resulting retardation, slack waters, and oscillations, the introduction of the suspended matters from the Occoquan, and sea water from below, combined to make this section a most interesting and important one for study. The Possum Point cross section was selected with these new factors in mind.

At Maryland Point the river takes a sharp bend from south to nearly northeast, and there is a considerable sedimentation consequent upon change of direction and increase of sea water at this cross section. From this section, "Nanjemoy Reach," there is a straight stretch of 10 miles to Popes Creek, the Mathias Point cross section. Four miles below Popes Creek is Lower Cedar Point, in the neighborhood of which is the uppermost limit of the oyster beds. The sections and stations below this to Higgins Point were selected with reference to distance from each other and such local sources of pollution as Colonial Beach.

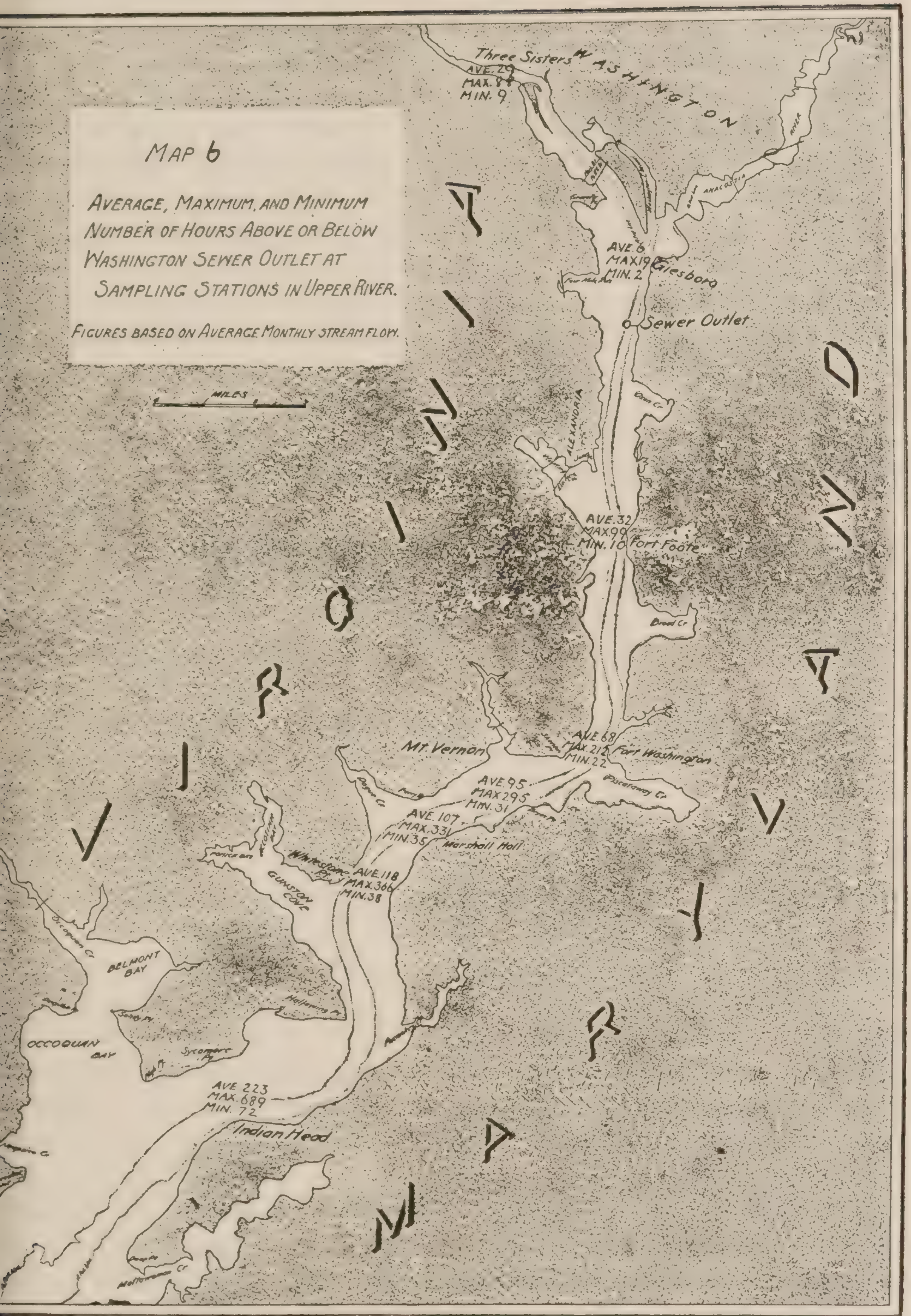
In table 37, page 179, will be found a list of the lower stations with distances, and their location will be found in maps Nos. 4, 5, and 6, page 178.

THE COLLECTION OF SPECIMENS.

The samples for bacteriological analysis were collected in cylindrical glass-stoppered bottles having a capacity of about 175 cubic centimeters. These bottles were carefully cleansed, the stoppers and necks covered with tin foil, each bottle wrapped in manila paper, and they were then kept in a hot-air sterilizer at 160° C. for over one hour, or in an autoclave at 120° C., for over 20 minutes. Vacuum tubes were also used for the collection of bacterial samples.


MAP 4
POINTS IN POTOMAC RIVER FROM WHICH SAMPLES FOR BACTERIOLOGICAL EXAMINATION WERE COLLECTED.
FIGURES INDICATE NUMBER OF SAMPLES COLLECTED FROM EACH POINT.
● = SURFACE SAMPLES.
○ = SURFACE AND DEEP SAMPLES.
MILES
THREE SISTERS
WASHINGTON
ANACOSTIA
GIESBORO PT.
SEWER OUTLET
ALEXANDRIA
FORT FOOTE
FORT WASHINGTON
MT. VERNON
MARSHALL HALL
WHITESTONE
GUNSTON COVE
BELMONT BAY
OCCOQUAN BAY
INDIAN HEAD
MARYLAND
VIRGINIA
142
196
40
209
170
52
57
177
420
173
119
430
180
179
178
174
426
64
122
87
62
178
86
58
133
66
40
69
22
67
39


MAP 5 SHOWING POINTS IN POTOMAC RIVER FROM WHICH SAMPLES OF OYSTERS AND WATER FOR BACTERIOLOGICAL ANALYSIS WERE COLLECTED.
● = OYSTERS SAMPLED. NUMERALS = NUMBER SAMPLES.
○ = WATER SAMPLED.
◉ = OYSTERS AND WATER SAMPLES TAKEN AT SAME POINT.
MARYLAND
VIRGINIA
CHESAPEAKE BAY
Quantico
Cockpit Pt.
Mattawoman Cr.
Popes Cr.
Swan Pt.
St. Margaret Id.
St. Catherine Id.
Heron Id.
Blakistone Id.
BRETON
Leonardtown
NOMINI BAY
Church Pt.
Cliffs
Ragged Pt.
Kinsale
St. Mary
Priests Pt.
St. Georges Id.
Hog Id.


MAP 6
AVERAGE, MAXIMUM, AND MINIMUM NUMBER OF HOURS ABOVE OR BELOW WASHINGTON SEWER OUTLET AT SAMPLING STATIONS IN UPPER RIVER.
FIGURES BASED ON AVERAGE MONTHLY STREAM FLOW.
MILES
Three Sisters
AVE. 29
MAX. 88
MIN. 9
WASHINGTON
ANACOSTIA
AVE. 6
MAX. 19
MIN. 2
Giesboro
Sewer Outlet
ALEXANDRIA
AVE. 32
MAX. 99
MIN. 10
Fort Foote
Broad Cr.
Mt. Vernon
AVE. 68
MAX. 212
MIN. 22
Fort Washington
Piscataway Cr.
AVE. 95
MAX. 295
MIN. 31
AVE. 107
MAX. 331
MIN. 35
Marshall Hall
Whitestone Pt.
AVE. 118
MAX. 366
MIN. 38
GUNSTON COVE
BELMONT BAY
OCCOQUAN BAY
Sycamore Pt.
AVE. 223
MAX. 689
MIN. 72
Indian Head
VIRGINIA
MARYLAND

The sample bottles for the determination of dissolved oxygen were of clear Bohemian glass with glass stoppers, having a capacity of 250 cubic centimeters.

The surface samples were collected by placing the unstoppered bottle in the holder shown by the cut (fig. 11). Various kinds of apparatus for the collection of deep samples were tried from time to time, including the Esmarch instrument, which was not found efficient for very accurate work; the vacuu mtubes with curved nicked necks, such as were used by the Metropolitan Sewage Commission, and apparatus designed by us and illustrated herewith. None answered all requirements, but for accurate bacteriologic samples, where only small quantities of water are required, the vacuum tubes, though fragile and difficult to handle in icy waters, are undoubtedly better than more elaborate apparatus, and are recommended for similar work elsewhere. The tubes used in this investigation were made in the laboratory from ordinary test tubes, but they may be purchased at small cost (4 or 5 cents each) when they are to be used in large numbers.

For the taking of samples for dissolved-oxygen determinations none of the methods heretofore used seemed applicable for this investigation, because it was desired to make an intensive study of a large number of samples from the same area, and because duplicate samples were needed.

An apparatus (figs. Nos. 12 and 13) was therefore designed, which consists primarily of a brass cylinder of such size as to hold about five times the contents of two of the bottles used for the collection of the samples. In the bottom of the cylinder are two holes about three-fourths of an inch in diameter. Below each of these is a soft rubber gasket, against which the neck of the bottle is held by means of a coiled spring beneath the bottle. Soldered into the top of the cylinder are two brass tubes, which extend through the holes in the bottom of the cylinder, so that they will be near the bottoms of the two bottles when they are in contact with the cylinder. Another tube, of larger diameter, extends about 3 inches above the top of the cylinder. To the cylinder is riveted a semicircular bucket handle, to which is fastened one end of a coiled spring, to the opposite end of which is fastened the rope for lowering and raising the apparatus. There is also attached to the top of the spring a small cord attached to a rubber stopper which fits the larger tube extending above the top of the cylinder. This cord is of such length that the weight of the apparatus filled will not extend the spring enough to pull out the cork, but when a sudden jerk is given the rope holding the apparatus the spring is extended, the small cord tightened, and the rubber stopper pulled out. Water then enters through the two tubes into the bottoms of the two sample bottles, displacing the air, which

escapes through the large upper tube until the large cylinder is filled and the pressure thus equalized. This procedure occupies about 60 to 90 seconds, and the apparatus is then hauled on deck. The hinged bottom, in which are the springs pushing the bottles against the cylinder gaskets, is now released, and one person removes the bottles and stoppers them as the second operator raises the apparatus.

By using three of these devices it is practicable to take surface, middle, and bottom samples in duplicate at the same time and station. As many as 76 samples were taken daily in this way over an extended period of time and dissolved oxygen determinations made therefrom.

When taking samples special care was exercised to avoid error due to contamination of samples for bacteriological examination. At cross sections both surface and bottom samples were taken at one or more stations and surface samples were taken as near the shore as was practicable. The bottles were marked with a wax pencil for identification and the same mark placed upon the following sample card, together with all available data as to tide, temperature, etc.:

Sample number, ________. Date collected, ________________________. Hour, __ a. m., __ p. m. Source, ____.
Wind, ____________________________. Weather, ______________________________.
Tide, ________________________________. Current flow, ___________________________.
Depth collected, ________. Temperature of water, ________. Turbidity, ________.
Chlorine, _____. Diss. oxy., _____. Diss. oxy., incubated, _____. Nitrites, _____.
Nitrates, ______.

Total bacteria on—				B. coli tests.		
Agar 37°, 24 hours.		Gelatin 20°, 4 hours.		Lactose bouillon at 37°, 48 hours.		
Amount used.	Total bacteria.	Amount used.	Total bacteria.	Amount used.	Per cent gas.	Endo.
Number per c. c. Agar............Gelatin....................				B. coli ....in..............c. c.		

Except in cold weather the bottles were immediately placed in a box containing ice and worked directly upon their arrival at the laboratory, which rarely exceeded three hours after they were taken. The samples collected by the steamship *Bratton* were plated and tubed almost immediately.

The tides and currents in the river, particularly in that section from Washington to Maryland Point, are not regular in interval or time, as are those of the open sea. They are variable, subject to

irregularities in time, force, and direction, dependent upon the relative strength and direction of the wind, the stream flow, and tidal influences, and hence can not be predicted even for a few hours ahead. Moreover, they differ at various stations at the same time, hence the system was adopted of starting out for the collection of samples at 8.30 a. m., instead of attempting it at certain phases of tide. The large number of samples taken and the long period during which the work continued enabled the investigators by this method to cover all phases of tide and current at each station and at the same time to return the samples to the laboratory during working hours.

Oysters were secured with tongs or a light dredge worked by hand; 15 or 20 of those best suited for sampling were carefully washed in water taken from over the bed and the sample was then placed in previously sterilized heavy cloth bags, marked for identification, and the data upon the following card were filled in:

Sample number, ________. Date collected, ________________________. Hour, __ a. m., __ p. m. Source, ____
Wind, ___________________________. Weather, ______________________________.
Tide, _________________________________. Current flow, __________________________.
Depth collected, ________. Temperature of water, ________. Turbidity, ________.
Chlorine, _____. Diss. oxy., _____. Diss. oxy., incubated, _____. Nitrites, _____.
Nitrates, ______.

Number of colonies on—				B. coli tests by—														
Agar 37°, 24 hours.		Agar 20°, 72 hours.		Lactose bile 37°, 72 hours.								Lactose broth 37°, 72 hours.						
Amount.	Count.	Amount.	Count.	Dilution.							Score.							Score.
				Oyster.	Gas.	Endo.	Gas.	Endo.	Gas.	Endo.		Gas.	Endo.	Gas.	Endo.	Gas.	Endo.	
....	....	....	....	1......	....	....	....	....	....	....	......	....	....	....	....	....	....	......
....	....	....	....	2......	....	....	....	....	....	....	......	....	....	....	....	....	....	......
....	....	....	....	3......	....	....	....	....	....	....	......	....	....	....	....	....	....	......
....	....	....	....	4......	....	....	....	....	....	....	......	....	....	....	....	....	....	......
....	....	....	....	5......	....	....	....	....	....	....	......	....	....	....	....	....	....	......
Colonies per c. c.: 20°, 37°					Rating=......							Rating=......						

In addition to these data, when practicable, a census of vessels and the personnel working over the oysters was made, and a large number of such records are given in connection with the detailed analysis of oyster samples.

For the purpose of collecting samples of mud from the channel an apparatus was designed by Sanitary Engineer Letton which consists

essentially of a cast-iron bell (fig. No. 14), having a base area of a square foot, or 929 square centimeters. A $1\frac{1}{4}$-inch inlet was provided for the surrounding water to enter, and radiating from this were pipes having one-eighth-inch perforation in the bottoms (fig. No. 15). The outlet, $1\frac{1}{2}$ inches in diameter, was connected to a rubber suction hose, which led to a rotary pump driven by a gasoline engine on deck. When the power pump was started the water from without entered the inlet, stirred up and suspended the top layer of mud confined in the bell, and this suspended matter was brought up through the hose and pumped into a graduated iron tank 2 feet square and 3 feet deep. Pumping was stopped when the water ran clear. A sample of the mixture was collected for analysis and the dilution of the 929 square centimeters of surface mud calculated. At the same time samples of the river water were taken, and from this the net bacterial count of the mud per centimeter of surface deduced. Chemical studies of this mixture were also made. The samples of water collected for bacteriological analysis were also used for the determination of turbidity.

Samples for chlorine determination were dipped up and placed in a hydrometer jar. Samples for plankton studies were collected near the surface in a 5-liter bottle attached to a pole, while deep or composite samples were pumped by a small, manually operated rotary pump through a one-half-inch hose. A cone-shaped iron dredge was used for collecting samples of surface mud in deep water, while in shallow water a shovel-shaped apparatus was used (fig. No. 16).

BACTERIOLOGICAL STUDIES.

The bacteriological data which were relied upon in this investigation as indices of pollution, were the total count of bacteria developing upon certain media and the prevalence of organisms of the *B. coli* group. It is not felt that these indices require defense in the present state of water bacteriology, since it is well understood that these data, in spite of drawbacks which have been urged by various observers, do give us fairly reliable and accurate notions of the sanitary conditions of water. The direct demonstration of the typhoid or other epidemic disease-causing organisms is impracticable, certainly as a routine, and other indices which have been suggested, such as the so-called sewage streptococci have not as yet established their value.

The technic employed conformed to the standard methods of the American Public Health Association. Lactose bouillon in Smith fermentation tubes were used for the detection of gas-forming organisms as a standard procedure. To these tubes, which contained about 25 c. c. of lactose broth, the water to be tested was added in three amounts, which were varied, after some experience, according

to the card data as to sampling station, tide, turbidity, and other determining factors. The amounts used were such as would most probably give one negative tube—that is, one which contained no gas. The tubes were incubated for 48 hours at 37° and then examined. Record was made on the card as to the amount of gas in the tube. From the highest dilution showing gas, and from the next one above, a loop of the culture was then spread with a loop upon the surface of an endo plate. At the end of 24 hours' incubation at 37° these endo plates were examined and all colonies showing a metallic sheen were considered *B. coli*. If the endo plates were negative, another series was carried on from the tubes, which had been preserved for that purpose, and the first endo plate was also kept for subsequent examination. Several hundred of the typical *B. coli* colonies were carried through a series of confirmatory tests, which are fully discussed later on. Many typhoid-like colonies were picked from the endo plates, but none had all of the cultural and agglutinative characteristics of *B. typhosus*.

Nutrient agar was used for the determination of the total bacterial count and the counts were made after 24 hours' incubation at 37°. Several plates were made of each sample and, always, duplicate plates of the middle dilution in the fermentation tube; for instance, if the amounts 10 c. c., 1 c. c., and 0.1 c. c. were used in the tubes, two plates with 1 c. c. were made, in addition to others if there was doubt as to proper dilution. Such dilution was made as would probably give a total count of approximately 200 or less. When possible the whole number of colonies on each plate were counted and the recorded result is an average of the two plates.

The value of gelatin medium for such purposes as learning the total count in filtration plants and for determining the total changes undergone by bacterial life in a body of water is fully recognized; but where the primary object is to secure an indication of the presence of organisms of intestinal origin, and therefore with an optimum temperature approximating that of the human body, nutrient agar at 37° is considered superior to gelatin at 20°. During the autumn months gelatin was almost useless for the lower-river work, in consequence of the number of liquefying bacteria present in the water. It was decided, in addition to the constant use of lactose broth and nutrient agar, to run a parallel series of lactose bile and gelatin, in order definitely to determine the camparative value of those media in work such as this on the Potomac River.

In another portion of the report will be found the analyses which show the comparative values of lactose broth and lactose bile, and a comparison of the results as interpreted by the so-called presumptive test, and by the confirmatory method with endo and other media used for a complete identification.

Both Smith and Durham fermentation tubes were used for the culture of gas-forming organisms. During the first few months of the investigation the Smith tubes were used exclusively; accurate observations were made of the percentage of gas formed and many analyses made as to the composition of the gas. In an extensive study, such as the present one, where the variations between different samples from the same stations are marked, it is more important to study the essential factors of as large a number of samples as possible than to expend energy and time upon what are proven to be unimportant and nonessential details. The chief objection raised against the use of the Durham tubes is that it is impracticable to determine accurately the percentage of gas formation.

A study of the results of confirmatory tests of those tubes which gave various percentages of gas showed that the tubes having percentages between 20 and 70 were undoubtedly more apt to contain *B. coli* than either those having the smaller amounts, which were due to the fermentation of muscles sugars by the proteus group, or those having larger percentages, which were almost always caused by a much more important group of lactose-splitting, spore-forming anaerobes, the occurrence and significance of which are fully discussed hereafter. Nevertheless an experience covering the examination of many thousands of fermentation tubes conclusively demonstrated that gas measurement alone is not a sufficiently reliable index to warrant a conclusion as to the identity of the gas-forming organism. Both of the above noncolon groups, however, are excluded by the use of aerobic endo plates, and because of the ease of making this determination and the accuracy of this one confirmatory test as compared to the slow and difficult procedure of confirmation by all the subculture tests, the Durham tube with endo confirmation was adopted, instead of the less accurate presumptive test.

Durham tubes were found to be economical of space, media, and time of inoculating, handling, and cleaning. They are less useful when 10 c. c. or more of water is to be tested. For making dilutions it was found very convenient to have 9 c. c. of water placed in each of many test tubes, which were then plugged with cotton and placed in the autoclave for 30 minutes at 120°. With proper care the quantity remained constant and was checked up frequently.

BACTERIOLOGICAL RESULTS—THE AGAR COUNTS.

The results of the few examinations of the waters of the upper river have already been given. Those of the lower river were very numerous, and will not be given in detail. There are many possible ways of presenting the large mass of data involved, and for purposes of rough orientation a table (12) of monthly averages by cross sections has been prepared. Averages of bacterial counts fail to give information as to that very important feature of successive

examinations—the variation. Nevertheless, from the table, the pollution resultant upon the entry of wastes from the cities at the upper end of this section of the river and its seasonal variation may be roughly gauged. The variations of results of successive daily, or at least frequent, examinations at a given station are, however, of the utmost importance when we attempt to estimate the sanitary status of a water. Two stations might give results which, when averaged, would be identical and yet be entirely different in character. In one case there might be a uniform moderate contamination and in the other an ordinarily exceptionally pure-water subject to occasional excessive pollution. The treatment of such waters in order to secure suitable supplies for domestic uses would be essentially different in the two cases. Table 13 shows the variation in the individual counts during quarterly periods at the various cross sections or sampling stations. It may be used for more intimate study of these variations as influenced by season and location in the course of the river. This table was prepared by classifying all of the contents in convenient groups, determining the number of counts for each station and quarter of the year falling in each of these groups, and then calculating in each instance what percentage of the total number of counts for that station and season this number represented. The percentages thus obtained are then added successively, beginning with the number of the greatest counts, and the totals entered opposite the appropriate group. Such an arrangement shows, for example, that at the Giesboro Point section during the quarter September to November all (100 per cent) of the counts were over 400, about half (53.4 per cent) were over 4,000, while only a few (3.4 per cent) were over 40,000.

Table 12.—*Monthly averages of bacteriological results by cross sections.*

[Cross section. Miles from Washington=nautical miles.]

Month.	Washington sewage, number of thousands of organisms.			Giesboro Point, 2 miles.			Fort Foote, 6 miles.			Fort Washington, 10 miles.		
	Agar.	Gelatin.	Colon per c.c. broth.	Agar.	Gelatin.	Colon per c.c. broth.	Agar.	Gelatin.	Colon per c.c. broth.	Agar.	Gelatin.	Colon per c.c. broth.
1913.												
June	....	....	....	9,500	....	316	5,700	....	207	1,700	....	133
July	....	....	....	10,000	....	375	7,200	....	291	1,200	....	26
August	4,300	3,200	204	12,500	15,500	617	7,800	11,500	313	550	1,400	34
September	6,700	10,300	250	8,300	8,800	306	4,000	4,600	124	550	500	24
October	4,400	5,900	303	12,000	17,500	389	6,300	10,500	348	1,800	1,300	98
November	2,000	3,300	80	6,800	18,000	231	4,400	15,000	242	3,600	8,500	202
December	1,200	7,800	185	4,300	....	199	5,500	....	367	3,700	....	167
1914.												
January	1,200	1,800	39	6,900	....	184	6,800	....	255	6,600	....	385
February	950	....	66	4,600	....	24	5,100	....	370	2,600	....	200
March	750	1,800	58	2,200	20,500	98	2,500	23,000	125	2,300	22,500	104
April	850	6,000	65	2,300	18,000	86	4,400	49,000	279	4,400	41,000	288
May	1,400	5,200	73	2,300	22,000	199	3,700	45,000	290	2,900	39,500	157

TABLE 12.—*Monthly averages of bacteriological results by cross sections*—Contd.

Month.	Mount Vernon, 12 miles.			Marshall Hall, 14 miles.			Whitestone Point, 15 miles.			Indianhead, 20 miles.		
	Agar.	Gelatin.	Colon per c. c. broth.	Agar.	Gelatin.	Colon per c. c. broth.	Agar.	Gelatin.	Colon per c. c. broth.	Agar.	Gelatin.	Colon per c. c. broth.
1913.												
June	1,700	....	94	....	....	....	....	....	....	....	....	....
July	650	....	16	....	....	....	....	....	....	....	....	....
August	400	950	15	325	400	48	....	....	....	....	....	....
September	....	....	....	275	1,700	24	....	....	....	....	....	....
October	....	....	....	1,200	2,800	85	....	....	....	....	....	....
November	....	....	....	2,400	5,700	137	....	....	....	....	....	....
December	....	....	....	1,900	....	64	2,500	....	115	1,600	....	95
1914.												
January	....	....	....	....	....	....	5,800	....	253	6,600	....	214
February	....	....	....	....	....	....	3,300	....	118	2,800	....	121
March	....	....	....	2,400	47,500	91	1,700	....	182	610	....	89
April	....	....	....	....	34,500	78	3,600	37,500	267	....	....	....
May	....	....	....	....	....	....	1,300	37,000	123	660	....	64

Month.	Possum Point, 24 miles.			Maryland Point, 42 miles.			Popes Creek, 53 miles.			Lower Cedar Point, 57 miles.			Below Lower Cedar Point to Point Lookout, 64 to 102 miles.		
	Agar.	Gelatin.	Colon per c. c. broth.	Agar.	Gelatin.	Colon per c. c. broth.	Agar.	Gelatin.	Colon per c. c. broth.	Agar.	Gelatin.	Colon per c. c. broth.	Agar.	Gelatin.	Colon per c. c. broth.
1913.															
June	......	......	....	......	......	....	......	......	....	......	......	....	......	......	....
July	......	......	....	......	......	....	......	......	....	......	......	....	......	......	....
August	......	......	....	85	120	0.04	90	50	0.07	......	......	....	29	......	0.01
September	......	......	....	75	75	.07	55	90	.06	43	50	0.03	50	62	.03
October	......	......	....	60	120	.11	40	100	.17	39	150	.03	42	176	.03
November	500	......	....	100	275	.75	65	170	.29	49	170	.14	21	120	.03
December	2,500	......	10	60	400	.32	40	220	.14	34	90	.08	24	119	.02
1914.															
January	2,500	......	117	275	1,300	6.9	140	800	1.2	65	400	.24	32	390	.10
February	2,200	......	138	450	......	4.7	50	1,100	.38	48	850	.06	39	509	.14
March	500	......	36	230	2,500	3.5	100	1,200	.28	62	950	.23	33	439	.04
April	......	......	....	150	750	.20	150	750	.17	110	800	.09	49	353	.04
May	500	......	10	120	1,100	.25	85	750	.12	85	650	.13	48	450	.07

TABLE 13.—*Distribution of agar results according to count.*

SEPTEMBER, OCTOBER, AND NOVEMBER, 1913.

Number of organisms per cubic centimeter.	Dalecarlia Inlet.		Three Sisters.		Pennsylvania Railroad Bridge.		Giesboro Point.		Fort Foote.		Fort Washington.		Marshall Hall.		Maryland Point.		Popes Creek.		Lower Cedar Point.		Below Cedar Point.	
	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.
0-10															1	100.0	2	100.0	4	100.0	131	100.0
10-20															6	99.7	22	99.4	23	98.3	359	86.0
20-30	3	100.0													22	97.7	56	92.4	69	88.8	194	47.8
30-40	8	95.9													32	90.4	57	74.6	53	60.0	72	27.1
40-50	1	85.1													50	79.9	69	56.8	36	37.9	54	19.4
50.75	6	83.8	1	100.0									2	100.0	89	63.4	64	34.6	39	28.9	58	13.6
75-100	5	75.5	1	98.6							1	100.0	2	99.3	54	34.0	23	7.3	7	6.7	28	7.5
100-125	3	68.9	1	97.3							0	99.7	19	98.6	22	16.1	11	6.7	4	3.7	12	4.5
125-150	4	64.9	1	95.9							4	99.7			9	8.9	2	3.5	1	2.1	4	3.2
150-175	4	59.5	0	94.5							10	98.3	21	91.9	4	5.9	1	2.9	0	1.6	4	2.8
175-200	4	54.0	0	94.5	1	100.0					4	94.8			3	4.6	1	2.5	2	1.6	3	2.3
200-225	6	48.7	2	94.5	0	99.3					5	93.4	34	84.5	1	3.6	0	2.2	0	0.8	3	2.0
225-250	4	40.5	1	91.8	3	99.3					7	91.6			1	3.3	1	2.2	0	0.8	3	1.7
250-300	4	35.1	2	90.4	2	97.3			1	100.0	22	89.2	25	72.5	3	3.0	2	1.9	1	0.8	2	1.4
300-350	3	29.7	1	87.7	2	95.9			0	99.7	13	81.5	14	63.7	1	2.0	0	1.3	0	0.4	2	1.2
350-400	3	25.7	2	86.3	3	94.6			1	99.7	18	77.0	8	58.8	3	1.7	0	1.3	0	0.4	3	1.0
400-450	3	21.6	2	83.6	2	92.5	1	100.0	0	99.3	10	70.7	8	56.0	0	0.7	2	1.3	1	0.4	2	0.6
450-500	1	17.6	1	80.8	4	91.2	0	99.7	0	99.3	14	67.2	9	53.2	0	0.7	0	0.6			1	0.4
500-600	1	16.2	2	79.4	6	88.5	1	99.7	3	99.3	13	62.4	10	50.0	1	0.7	0	0.6			3	0.3
600-700	2	14.9	5	76.7	6	84.5	2	99.3	3	98.3	7	57.8	4	46.5	0	0.3	1	0.6				
700-800	2	12.2	4	69.9	7	80.4	3	98.7	4	97.3	9	55.4	4	45.1	1	0.3	1	0.3				
800-900	0	9.5	2	64.4	6	75.6	4	97.6	6	95.9	9	52.3	6	43.7								
900-1,000	1	9.5	6	61.6	19	71.6	2	96.3	1	93.8	3	49.1	3	41.5								
1,000-1,500	3	8.1	9	52.4	18	58.8	13	95.6	19	83.4	15	48.1	8	40.5								
1,500-2,000	2	4.1	6	41.1	17	46.6	20	91.2	19	86.9	16	42.7	28	37.7								
2,000-2,500	1	1.4	5	32.8	13	35.1	26	84.3	26	80.3	22	37.3	25	27.8								
2,500-3,000			4	26.0	11	26.4	25	75.5	27	71.4	14	29.7	13	19.0								
3,000-3,500			5	20.5	10	18.9	17	67.0	25	62.1	17	24.7	11	14.4								

TABLE 13.—*Distribution of agar results according to count*—Continued.

SEPTEMBER, OCTOBER, AND NOVEMBER, 1913—Continued.

Number of organisms per cubic centimeter.	Dalecarlia Inlet.		Three Sisters.		Pennsylvania Railroad Bridge.		Giesboro Point.		Fort Foote.		Fort Washington.		Marshall Hall.		Maryland Point.		Popes Creek.		Lower Cedar Point.		Below Cedar Point.	
	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.
3,500–4,000			1	13.7	6	12.2	23	61.2	14	53.4	13	18.8	6	10.6								
4,000–4,500			1	12.3	2	8.1	18	53.4	23	48.6	9	14.3	8	8.5								
4,500–5,000			1	11.0	4	6.8	13	47.3	19	40.7	10	11.1	3	5.6								
5,000–6,000			4	9.6	4	4.1	26	42.8	17	34.1	11	7.7	6	4.6								
6,000–7,000			1	4.1	2	1.4	14	34.0	24	28.3	5	3.8	3	2.5								
7,000–8,000			0	2.7			12	28.3	12	20.0	2	2.1	2	1.4								
8,000–9,000			0	2.7			4	25.2	12	15.9	2	1.4	0	0.7								
9,000–10,000			1	2.7			9	23.8	9	11.7	2	0.3	1	0.7								
10,000–15,000			0	1.4			16	20.8	13	8.5			1	0.4								
15,000–20,000			1	1.4			11	15.3	7	4.1												
20,000–25,000							4	11.6	3	1.7												
25,000–30,000							3	10.2	1	0.7												
30,000–35,000							6	3.4	1	0.3												
35,000–40,000							6	3.4														
40,000–45,000							4	3.4														
45,000–50,000							1	3.4														
50,000–60,000							6	3.4														
60,000–70,000							1	1.4														
70,000–80,000							1	1.0														
80,000–90,000							2	0.7														
Number of samples	74		73		148		294		290		287		284		303		315		240		938	

TABLE 13.—*Distribution of agar results according to count*—Continued.

DECEMBER, 1913, JANUARY AND FEBRUARY, 1914.

Number of organisms per c. c.	Giesboro Point.		Fort Foote.		Fort Washington.		Whitestone Point.		Indianhead.		Possum Point.		Maryland Point.		Popes Creek.		Lower Cedar Point.		Below Lower Cedar Point.	
	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.
0–10																			45	100.0
10–20													1	100.0	7	100.0	7	100.0	165	91.8
20–30													16	99.6	23	95.0	25	93.3	131	61.8
30–40													19	90.2	32	80.9	17	69.5	86	38.0
40–50													12	79.2	32	64.8	18	53.3	40	22.4
50–75											1	100.0	19	72.3	29	46.6	20	36.0	53	15.1
75–100											2	99.2	26	61.7	20	30.1	11	17.1	22	5.5
100–125											2	97.6	14	46.2	15	18.8	7	6.7	5	1.5
125–150											4	46.1	8	38.3	6	10.2			0	.55
150–175											3	92.9	10	33.5	2	6.8			0	.55
175–200	1	100.0									3	90.6	6	27.7	1	5.7			0	.55
200–225	0	98.6			2	100.0	2	100.0	1	100.0	2	88.2	6	24.3	2	5.1			1	.55
225–250	0	88.6							1	99.2	2	86.6	5	20.8	0	4.0			0	.36
250–300	0	98.6							1	98.4	3	85.0	3	17.9	0	4.0			2	.36
300–350	0	98.6			0	96.9	0	97.8	0	97.5	6	82.7	3	16.2	0	4.0				
350–400	0	98.6							0	97.5	3	78.0	3	14.5	0	4.0				
400–450	2	98.6			1	96.9	1	97.8	1	97.5	3	75.6	4	12.7	1	4.0				
450–500									2	96.7	3	73.2	1	10.4	0	3.4				
500–600	0	95.8	1	100.0	0	95.3	0	96.7	2	95.1	3	70.9	3	9.8	1	3.4				
600–700	1	95.8	0	98.7					1	93.4	3	68.5	3	8.1	1	2.8				
700–800	3	94.4	0	98.7	0	95.3	2	96.7	1	92.6	3	66.1	2	6.4	2	2.3				
800–900	1	90.2	0	98.7					4	90.7	4	63.8	2	5.2	1	1.1				
900–1,000	2	88.8	0	98.7					3	88.5	2	60.6	0	4.0	1	.6				
1,000–1,500	9	85.9	2	98.7	1	95.3	7	44.5	17	85.0	13	59.1	4	4.0	1	.6				
1,500–2,000	3	73.2	3	96.1	2	93.8	7	86.8	13	71.9	16	48.8	2	1.7						
2,000–2,500	3	69.0	4	92.3	8	90.6	8	79.1	8	61.2	10	36.2	0	.6						
2,500–3,000	6	57.7	4	76.9	7	71.9	5	61.5	7	48.0	2	22.8	1	.6						
3,000–3,500	6	49.3	9	71.8	9	60.9	13	56.0	3	42.1	5	21.3								
3,500–4,000	5	40.8	8	60.2	2	46.9	3	41.7	11	39.7	6	17.3								
4,000–4,500	4	33.8	4	50.0	6	43.7	3	38.4	5	30.6	3	12.6								

TABLE 13.—*Distribution of agar results according to count*—Continued.

DECEMBER, 1913, JANUARY AND FEBRUARY, 1914—Continued.

Number of organisms per c. c.	Giesboro Point.		Fort Foote.		Fort Washington.		Whitestone Point.		Indianhead.		Possum Point.		Maryland Point.		Popes Creek.		Lower Cedar Point.		Below Lower Cedar Point.	
	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in grou p.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.
4,500–5,000	2	28.2	8	44.9	2	34.4	7	35.2	11	26.4	5	10.2	......	......	......	......	......	......	......	......
5,000–6,000	3	25.4	5	34.6	4	31.2	6	27.5	6	17.4	4	6.3	......	......	......	......	......	......	......	......
6,000–7,000	2	21.1	4	28.2	3	25.0	8	20.9	2	12.4	1	3.1	......	......	......	......	......	......	......	......
7,000–8,000	1	18.3	6	23.1	4	20.3	1	12.1	3	10.7	1	2.4	......	......	......	......	......	......	......	......
8,000–9,000	1	16.5	5	15.4	3	14.1	2	11.0	2	8.3	2	1.6	......	......	......	......	......	......	......	......
9,000–10,000	8	15.5	5	9.0	5	9.4	3	8.8	6	6.6	......	......	......	......	......	......	......	......	......	......
10,000–15,000	3	4.2	2	2.6	1	1.6	4	5.5	1	1.7	......	......	......	......	......	......	......	......	......	......
20,000–25,000	......	......	......	......	......	......	1	1.1	1	.8	......	......	......	......	......	......	......	......	......	......
Number of samples	71	......	78	......	64	......	91	......	121	......	127	......	173	......	176	......	105	......	550	......

TABLE 13.—*Distribution of agar results according to count*—Continued.

MARCH, APRIL, AND MAY, 1914.

Number of organisms per c. c.	Giesboro Point.		Fort Foote.		Fort Washington.		Whitestone Point.		Indianhead.		Possum Point.		Maryland Point.		Popes Creek.		Lower Cedar Point.		Below Lower Cedar Point.	
	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.
0-1																			10	100.0
10-20															2	100.0	4	100.0	110	98.8
20-30											1	100.0	1	100.0	6	99.2	12	97.2	209	85.5
30-40											1	98.8	1	99.5	29	96.6	30	88.8	136	60.0
40-50									1	100.9	0	97.7	1	98.9	24	84.4	28	67.9	111	43.6
50-75									9	99.1	5	97.7	26	98.4	69	74.2	29	51.7	146	30.2
75-100									4	91.1	3	92.1	32	84.2	28	44.9	14	31.5	55	12.5
100-125					1	100.0			8	87.4	6	88.0	32	66.8	27	33.0	8	21.7	13	5.8
125-150					0	99.3			1	80.2	1	81.8	12	49.4	11	21.6	5	16.1	3	4.2
150-175					0	99.3			3	79.4	5	80.8	17	42.9	14	17.0	5	12.6	5	3.9
175-200					0	99.3			0	76.7	1	75.1	6	33.7	10	11.0	1	9.1	6	3.2
200-225	1	100.0			0	99.3	1	100.0	5	76.7	4	74.0	16	30.5	5	6.4	2	8.4	7	2.5
225-250	0	99.4			0	99.3	0	99.4	4	72.2	3	69.5	3	21.7	0	4.7	2	7.0	1	1.7
250-300	0	99.4			1	99.3	1	99.4	3	68.6	1	66.1	8	20.2	1	4.7	1	5.6	2	1.6
300-350	2	99.4			1	98.6	1	99.0	6	66.0	12	65.0	8	15.8	3	4.2	3	4.9	2	1.3
350-400	3	98.1			1	97.8	0	98.4	6	60.8	9	51.6	4	11.4	0	3.0	2	2.8	2	0.9
400-450	2	95.3			1	97.1	1	98.4	9	55.3	8	41.5	3	9.2	0	3.0	2	1.4	2	0.9
450-500	3	94.8			0	96.4	2	97.9	12	47.3	2	32.5	5	7.6	0	3.0			1	0.6
500-600	12	91.8			1	96.4	5	96.8	11	36.5	4	30.6	3	4.9	0	3.0			2	0.5
600-700	7	85.0	2	100.0	4	95.6	7	94.2	6	26.8	7	25.8	2	3.3	1	3.0			0	0.2
700-800	16	80.4	1	98.7	7	92.7	4	90.2	5	21.4	3	17.9	2	2.2	2	2.5			0	0.2
800-900	10	70.6	2	98.2	4	87.5	8	88.4	3	19.0	3	14.6	0	1.1	1	1.7			2	0.2
900-1,000	5	63.4	2	97.8	4	84.6	14	84.2	1	14.3	2	11.2	0	1.1	0	1.3				
1,000-1,500	25	60.1	23	95.6	12	81.6	42	76.9	8	13.4	5	9.0	1	1.1	1	1.3				
1,500-2,000	14	43.8	21	81.2	11	72.8	25	54.5	4	6.2	2	3.4	0	0.5	2	0.9				
2,000-2,500	8	34.6	16	68.1	9	64.7	23	41.3	0	2.7	0	1.1	1	0.5						
2,500-3,000	6	29.5	23	58.2	17	58.0	15	29.1	0	2.7	0	1.1								
3,000-3,500	5	25.5	9	43.7	12	45.5	15	21.2	0	2.7	1	1.1								
3,500-4,000	4	22.2	7	38.2	14	36.8	2	13.2	0	2.7										
4,000-4,500	6	19.6	9	33.7	3	26.9	2	12.2	0	2.7										

TABLE 13.—*Distribution of agar results according to count*—Continued.

MARCH, APRIL, AND MAY, 1914—Continued.

Number of organisms per c. c.	Giesboro Point.		Fort Foote.		Fort Washington.		Whitestone Point.		Indianhead.		Possum Point.		Maryland Point.		Popes Creek.		Lower Cedar Point.		Below Lower Cedar Point.	
	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.
4,500–5,000	6	15.7	13	28.2	7	24.5	7	11.1	0	2.7	......	....	......	....	......	....	......	....	......	....
5,000–6,000	5	11.7	7	20.0	7	19.1	2	7.4	1	2.7	......	....	......	....	......	....	......	....	......	....
6,000–7,000	3	8.5	4	15.6	6	14.0	3	6.3	0	1.8	......	....	......	....	......	....	......	....	......	....
7,000–8,000	2	6.5	8	13.1	3	9.5	1	4.8	2	1.8	......	....	......	....	......	....	......	....	......	....
8,000–9,000	4	5.2	3	8.1	0	7.4	1	4.2	......	....	......	....	......	....	......	....	......	....	......	....
9,000–10,000	2	2.6	3	6.3	3	7.4	2	3.7	......	....	......	....	......	....	......	....	......	....	......	....
10,000–15,000	1	1.3	4	4.4	5	5.1	5	2.6	......	....	......	....	......	....	......	....	......	....	......	....
15,000–20,000	1	0.7	2	1.9	0	1.5	......	....	......	....	......	....	......	....	......	....	......	....	......	....
20,000–25,000	......	....	1	0.6	2	1.5	......	....	......	....	......	....	......	....	......	....	......	....	......	....
Number of samples	153	....	160	....	136	....	189	....	112	....	89	....	184	....	236	....	143	....	825	....

TABLE 13.—*Distribution of agar results according to count*—Continued.

JUNE, JULY, AND AUGUST, 1914.

Number of organisms per c.c.	Dalecarlia Inlet.		Three Sisters.		Pennsylvania Railroad Bridge.		Giesboro Point.		Fort Foote.		Fort Washington.		Mount Vernon.	
	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.
0–10	6	100.0												
10–20	12	92.1												
20–30	16	76.3												
30–40	6	55.3												
40–50	12	47.4	1	100.0									1	100.0
50–75	3	31.6	0	97.6									1	99.5
75–100	2	27.6	2	97.6	1	100.0					1	100.0	7	99.1
100–125	2	25.0	1	92.7	0	99.1					0	99.6	5	95.9
125–150	2	22.4	1	90.3	0	99.1					1	99.6	7	92.6
150–175	2	19.7	1	87.8	0	99.1	1	100.0			1	99.1	11	90.4
175–200	2	17.1	2	85.4	0	99.1	0	99.5	1	100.0	6	98.7	5	85.5
200–225	2	14.5	1	80.5	0	99.1	0	99.5	0	99.5	3	96.1	7	83.2
225–250	2	11.8	4	78.0	1	99.1	0	99.5	0	99.5	12	94.9	24	80.0
250–300	1	9.2	3	68.3	0	98.2	0	99.5	0	99.5	24	89.7	17	69.1
300–350	0	7.9	4	58.5	2	98.2	0	99.5	0	99.5	25	79.4	13	61.4
350–400	0	7.9	4	51.2	0	96.4	0	99.5	0	99.5	9	68.7	16	55.4
400–450	0	7.9	2	41.5	1	96.4	2	99.5	1	99.5	9	64.8	3	48.2
450–500	3	7.9	2	36.6	1	95.5	2	98.6	3	99.1	19	60.9	16	46.8
500–600	0	3.9	1	31.7	1	94.6	2	97.6	5	97.6	18	52.8	14	39.5
600–700	0	3.9	3	29.3	3	93.7	4	96.6	8	95.3	10	45.1	7	33.2
700–800	1	3.9	0	21.9	2	91.0	0	94.7	5	91.5	11	40.8	6	30.0
800–900	0	2.6	2	21.9	1	88.2	1	94.7	8	89.2	7	36.0	8	27.3
900–1,000	2	2.6	2	17.1	18	87.3	17	94.2	24	85.4	28	33.0	21	23.6
1,000–1,500			0	12.2	7	72.1	7	85.9	10	74.2	15	21.0	11	14.1
1,500–2,000			2	12.2	12	65.8	12	82.5	16	69.5	10	14.6	6	9.1
2,000–2,500			2	7.3	7	55.0	8	76.7	10	62.0	11	10.3	5	6.4
2,500–3,000			0	2.4	4	48.6	9	72.8	7	57.3	4	5.6	2	4.1
3,000–3,500			0	2.4	4	45.1	9	68.4	10	54.0	1	3.9	1	3.2
3,500–4,000			0	2.4	8	41.4	3	64.1	7	49.3	3	3.4	0	2.7
4,000–4,500			0	2.4	2	34.2	1	62.4	9	46.0	1	2.1	1	2.7
4,500–5,000			0	2.4	6	32.4	13	62.1	9	41.8	1	1.7	2	2.3
5,000–6,000			0	2.4	6	27.0	9	55.8	12	37.6	1	1.3	2	1.4
6,000–7,000			0	2.4	2	21.6	9	51.4	10	31.9	2	0.9	0	0.5

TABLE 13.—*Distribution of agar results according to count*—Continued.

JUNE, JULY, AND AUGUST, 1914—Continued.

Number of organisms per c.c.	Dalecarlia Inlet.		Three Sisters.		Pennsylvania Railroad Bridge.		Giesboro Point.		Fort Foote.		Fort Washington.		Mount Vernon.	
	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.	Number in group.	Per cent greater than lowest group.
7,000–8,000	....	....	0	2.4	4	19.8	14	47.1	6	27.2	....	....	1	0.5
8,000–9,000	....	....	0	2.4	4	16.2	4	40.3	7	24.4	....	....	....	....
9,000–10,000	....	....	1	2.4	5	12.6	36	38.3	24	21.1	....	....	....	....
10,000–15,000	....	....	....	....	3	8.1	19	20.8	7	9.9	....	....	....	....
15,000–20,000	....	....	....	....	2	5.4	6	11.7	4	6.6	....	....	....	....
20,000–25,000	....	....	....	....	2	3.6	5	8.7	3	4.7	....	....	....	....
25,000–30,000	....	....	....	....	1	1.8	3	6.3	2	3.3	....	....	....	....
30,000–35,000	....	....	....	....	0	0.9	4	4.9	2	2.3	....	....	....	....
35,000–40,000	....	....	....	....	0	0.9	1	2.9	1	1.4	....	....	....	....
40,000–45,000	....	....	....	....	1	0.9	0	2.4	0	1.0	....	....	....	....
45,000–50,000	....	....	....	....	....	....	1	2.4	1	1.0	....	....	....	....
50,000–60,000	....	....	....	....	....	....	1	1.9	0	0.5	....	....	....	....
60,000–70,000	....	....	....	....	....	....	1	1.5	0	0.5	....	....	....	....
80,000–90,000	....	....	....	....	....	....	2	1.0	1	0.5	....	....	....	....
Number of samples	76	....	41	....	111	....	206	....	213	....	233	....	220	....

A graphic method of showing the variation in the numbers enecountered at each station is given in charts E, F, G, and H. Here the counts for stations and periods, as in Table 13, have been similarly arranged in groups and then plotted in curves on a logarithmic scale, which enables the high counts to be included in convenient space. In these charts the more nearly vertical the curves run the less the variation in the counts for a given station will be, and the more nearly the curves are parallel to each other the more nearly does the type of variation at the different stations conform. Since the intensity of pollution is indicated in these charts by the distance from the left-hand margin which a given curve occupies, the pollution introduced near Giesboro Point to the water as it comes downstream from Three Sisters, and the progressive purification taking place as one proceeds down the river, can be readily appreciated. Since the area between the curves corresponds to the drop in the number of bacteria, it is evident that the water is considerably purified in the area between the sewer outlet and Mount Vernon. During the next three months there is a change in the form of the curves for Fort Washington and Mount Vernon. They become compound curves, showing along the upper half of their length a tendency to repeat the form of the preceding three months, but shifting at the lower end to a position comparable to the next three months of high-stream flow.

The river is thus seen to change from a summer phase to a wet, winter phase. During the next three months this movement becomes general. Stations as far down the river as Indianhead, which during the summer months showed a very considerable purification over the condition at Fort Washington, become during December, January, and February almost as bad as the up-river stations. Indeed, the curve of Possum Point advances to a position beyond that held previously by Fort Washington. As in the case of the decrease in the number of *B. coli* already discussed, this is due to, and almost wholly explained by, the high-stream flow and the shortened time required for the water to reach these stations. The first effects are noticed at Maryland Point, and even the other lower-river stations, where the curves begin to swing or skew toward the higher counts. During March, April, and May the upper-river stations show a progressive return to summer conditions. The lower stations, however, due to lag, show the full effects of the wave of rapid flow. The curves at these places round out to a normal form of the worst condition of the water, the upper part of the curve advancing to a true proportion with the lower part. These curves thus describe the continuous wavelike progression of the changing movement of the water and the changing condition of the water due to the change in time. The averages of the agar counts follow the formula developed for the

B. coli results and show that they also may be explained to a larg
extent by the time factor.

The agar counts compared to the colon determinations.—The colon
averages given in this report are calculated from the fermentation
tube results according to the method proposed by Phelps—a metho
which, if susceptible of error like all proposed procedures, neverthe-
less gives us the most practicable and reliable means of expressing
the results based on a large bulk of data. To quote Phelps:

> The principle upon which this method of calculation is based is this: If a series of dilutions are made from a given water and these dilutions submitte to appropriate tests, giving positive or negative results, the most probable valu of the actual numbers of organisms present is indicated by the reciprocal o the greatest dilution giving a positive test. For example, if dilutions of 0.1 .01, and .001 c. c. are investigated, and a positive result obtained on the firs two and not on the last, the most probable number of bacteria present in th water is 100.

In the present investigation the colon averages based on figures thu calculated have borne an astonishingly constant relation to the aga counts for the same sampling stations. In Table 14 these ratios ar presented, and they show that for all stations down to Marylan Point the relation of *B. coli* to the total agar count is about 5 to 100 Below this point the number of *B. coli* becomes so small that th ratio is distinctly changed. At Maryland Point the river commence to be distinctly salt, and the contamination in these lower areas is s slight that local chance pollutions may readily sway the results an cause the observed irregularities.

TABLE 14.—*Number of B. coli to each 100 colonies on agar 37°, by months an cross sections.*

Cross section.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Sewage	......	......	4.75	3.73	6.89	4.00	15.42	3.25	6.95	7.65	7.64	5.21
Giesboro Point	3.36	3.75	4.94	3.69	3.25	3.40	4.63	2.67	.52	4.45	3.74	8.66
Fort Foote	3.63	4.05	4.01	3.10	5.52	5.50	6.56	3.75	7.23	5.00	6.34	8.66
Fort Washington	7.65	2.17	6.18	4.37	5.44	5.58	4.51	5.83	7.69	4.52	6.54	5.41
Mount Vernon	5.53	2.46	3.75	......	......	......	......	......	......	......	......	......
Marshall Hall	1.48	8.73	7.08	5.71	3.37	......	......	......	......	3.79	......	......
White Point	......	......	......	......	......	......	4.60	4.36	3.58	1.07	7.42	9.46
Indianhead	......	......	......	......	......	......	5.94	3.24	4.32	1.46	......	9.70
Possum Point	......	......	......	......	......	......	2.00	4.68	6.27	7.20	......	2.00
Average	4.33	4.25	5.12	4.12	4.89	4.62	6.22	3.97	5.22	4.39	6.34	6.89
Maryland Point	......	......	.047	.093	.183	.750	.530	2.51	1.05	1.52	.133	.21
Popes Creek	......	......	.078	.109	.425	.447	.350	.857	.760	.280	.113	.14
Lower Cedar Point	......	......	......	.069	.076	.290	.235	.369	.125	.371	.082	.13
Below Lower Cedar Point	......	......	.035	.060	.072	.143	.083	.313	.359	.121	.082	.14
Average below Possum Point	......	......	.052	.081	.189	.239	.300	1.01	.574	.573	.103	.16

General average of sections above Maryland Point for the year 5.070; general average of sections below Maryland Point for the year, 0.338.

Sufficient bacteriological evidence has now been presented so that the degree of pollution of the lower river can be appreciated. From this point onward the separate consideration of the pollution and the purification of the stream is scarcely feasible. Reference is therefore made to the section on "Purification," for a continuation of the subject. Before leaving the subject of bacteriology, however, it seems pertinent to insert at this point certain observations on methods and their results, which were made during the investigation.

ASSOCIATED BACTERIOLOGICAL OBSERVATIONS.

Observations on gas-producing, spore-forming anærobes.—It was early observed that there was a difference in the significance of gas-formation in lactose broth fermentation tubes, according to whether this was found in the water from near the upper portion of the lower river or from the lower stations. Gas in fermentation tubes from the vicinity of Washington was nearly always confirmed as indicating the presence of *B. coli*, by giving a positive reaction on endo medium, whereas in the lower part of the river where larger amounts of water had to be used to secure fermentation, such confirmation failed in the great majority of cases. Suspected differences in the methods used were eliminated by having the same person perform the work, using identical media, the results remaining as before. Plates made at the lower stations from tubes showing gas frequently developed no growth whatever, or if colonies developed they were usually of bacteria of the subtilis group. This indicated that there was present some organism splitting lactose in the fermentation tube which would not even grow on the endo plate. The discrepancy in the results at the upper and lower stations is given in Table 15 and graphically shown in Chart F.

TABLE 15.—*Gas-forming organisms from various stations confirmed or not as being B. coli.*

Cross sections.	Number of samples.	Average number of B. coli per c. c.	Average number of gas formers, not B. coli, per c. c.	B. coli, percentage of total gas formers.
Giesboro Point	770	295	24.1	92.4
Fort Foote	789	254	9.7	96.3
Fort Washington	778	123	6.2	95.2
Mount Vernon to Whitestone Point	851	102	8.5	92.3
Indianhead	241	123	15.7	88.6
Possum Point	212	66.2	13.8	82.7
Maryland Point	691	1.44	.75	65.7
Popes Creek	740	.19	.33	36.5
Lower Cedar Point	476	.14	.16	46.6
Below Lower Cedar Point	2,261	.052	.057	47.5

The almost parallel diminution in the number of *B. coli* and the percentage of confirmed fermented tubes is discussed in the section comparing lactose bile and lactose broth results, where it becomes evident that another organism besides *B. coli* so affects the presumptive test in both of these media as to render it very unreliable except in the highly polluted parts of the river.

A microscopic examination of the tubes which gave no growth on the endo agar showed large, plump, nonmotile bacteria. When inoculated into another tube these organisms always produced gas, and usually in large amounts. Indeed, a rather consistent characteristic was their pronounced gas formation from 50 to 100 per cent. They also gave vigorous gas formation when inoculated into plain agar tubes by the stab method.

These facts indicate that the organism found at the lower-river stations, which caused gas formation and failed to grow on the plates, must belong to the large group of anaerobes, such as *B. welchii*, *äerogenes capsulatus*, *enteritidis sporogenes*, etc., which have been isolated in many cases from water and soil. Many of these organisms form spores, which would explain their persistence in the water of the lower river. To confirm this conclusion many samples of river water, sewage, and feces were heated for 10 minutes at 80°, and then inoculated in freshly sterilized lactose broth. The river water showed gas in from 1 to 5 c. c., sewage usually in 0.01 c. c., while fresh feces varied, seldom giving it in 0.001 c. c., but usually in quantities less than 0.1 c. c. Vigorous fermentation was characteristic, though plating yielded no *B. coli*, nor would it be expected after this treatment. About 1 c. c. of these broth cultures was inoculated into the ears of several rabbits, which were killed shortly after and incubated at 37° according to the technique described by Welch. After 24 hours they showed a typical appearance, being distended to an enormous size, the blood being forced from the nose by the gas pressure, and the skin filled with gas. On post mortem they showed the typical gas-blown liver, and the veins were bloodless and filled with gas. Cultures from the heart readily fermented lactose broth and plain agar "shake" tubes. Under the microscope the organism showed large nonmotile bacteria varying in length and as regards chain formation.

These results proved beyond reasonable doubt that the bacteria which were fermenting such a large number of tubes at the lower-river stations belonged to a general group of lactose-fermenting anaerobes, most of which form spores. The frequency with which the tubes indicated the presence of these forms makes evident the importance of knowing their source, distribution, and significance. Many advocates of the presumptive test maintain that they are of sewage origin, and therefore have the same significance as *B. coli*,

and that they should be included with them in interpreting an analysis. But even if they do come from sewage (and it has not been proved that this is the only source) it still does not necessarily follow that they have the same significance as *B. coli*. A different life history, and in particular the fact that they form spores certainly would make it impossible to give the same interpretation to the condition of a water containing these organisms only as to one in which *B. coli* are also present.

While the latter die out rapidly in a river, the spores of the anaerobes persist for long periods and distances; hence they may indicate pollution so remote as to be no longer dangerous. In order to study the occurrence of this important group, a simple technique was employed for separating from them the nonspore forming *B. coli* group. Durham tubes, which had been steamed for half an hour, to expel any traces of free oxygen, were kept in a bath at a constant temperature of 70° (fig. 17). The water tested was then put into these hot tubes and kept at this temperature for 10 minutes, then removed and incubated at 37° until gas formed. Ordinarily 18 hours was the interval before gas appeared, though sometimes 3 or 4 days elapsed before its appearance, and for this reason all tubes were incubated 4 days before calling them negative. The longer time necessary for the first appearance of gas from such spore-bearing organisms is rather strikingly different from that required for *B. coli*, for the latter is usually fermenting vigorously in 12 hours. After gas begins to appear in the former, however, it is formed very rapidly, so that in a few hours the closed arm is usually full of gas, or nearly so.

Such tubes as showed gas after the above treatment were promptly plated upon endo, but the plates in every case showed no growth, or had the wrinkled scum of a subtilis-like growth.

The following is a tabulation of the results obtained by the above-described procedure:

TABLE 16.—*Results of tests for lactose-fermenting, spore-forming anaerodes, 1915.*

Place and date.	Cubic centimeters tested.	Gas.	Cubic centimeters tested.	Gas.	Cubic centimeters tested.	Gas.	Average number per cubic centimeter.	Station average.
Lower Cedar Point:								
Mar 22	10	+	5	—	1	—	0.1	0.05
Mar. 24	1	+	1	+	1	—	.66	
Mar. 25	1	+	1	+	1	—	.66	
Popes Creek:								
Mar. 22 c	5	+	2	+	1	+	1 +	1
Mar. 22 d	5	+	2	+	1	—	.5	
Mar. 24	1	+	1	+	1	+	1 +	
Mar. 25	1	+	1	+	1	+	1 +	
Mar. 28	1	+	1	+	1	—	.66	

TABLE 16.—*Results of tests for lactose-fermenting, spore-forming anaerobes, 1915*—Continued.

Place and date.	Cubic centimeters tested.	Gas.	Cubic centimeters tested.	Gas.	Cubic centimeters tested.	Gas.	Average number per cubic centimeter.	Station average.
Maryland Point:								
Mar. 22	5	+	2	+	1	−	0.5	
Mar. 24	1	+	1	+	1	+	1 +	
Mar. 24	1	+	1	+	1	+	1 +	1
Mar. 25	1	+	1	+	1	+	1 +	
Mar. 28	1	+	1	−	1	+	.66	
Sandy Point:								
Mar. 28	1	+	1	+	1	−	.66	.66
Possum Point:								
Mar. 22	1	+	1	+	1	+	1 +	
Mar. 24	1	+	1	+	1	+	1 +	1
Mar. 25	1	+	1	+	1	+	1 +	
Mar. 28	1	+	1	+	1	−	.66	
Indian Head:								
Mar. 22	1	+	1	−	1	−	.33	
Mar. 22	1	+	1	+	1	−	.66	
Mar. 24	1	+	1	+	1	+	1	.6
Mar. 25	1	+	1	−	1	−	.33	
Mar. 28	1	+	1	+	1	−	.66	
Whitestone Point:								
Mar. 24	1	+	1	+	1	−	.66	
Mar. 25	1	+	1	−	1	−	.33	.56
Mar. 28	1	+	1	+	1	−	.66	
Marshall Hall:								
Mar. 19	1	+	1	+	1	−	.66	
Mar. 20	½	+	½	+	½	+	2 +	
Mar. 23	½	+	½	+	½	−	1.33	
Mar. 25	½	+	½	+	½	+	2 +	
Mar. 28	½	−	½	−	½	−	.66−	.66
Mar. 31	½	+	½	+	½	−	1.33	
Apr. 2	½	+	½	+	......	......	2 +	
Apr. 3	½	+	½	+	½	+	2 +	
Fort Washington:								
Mar. 19	1	+	1	+	1	+	1 +	
Mar. 20	½	+	½	+	½	−	1.33	
Mar. 23	½	+	½	+	½	+	2 +	
Mar. 25	½	+	½	−	½	−	.66	1.4
Mar. 30	½	+	½	+	½	−	1.33	
Mar. 31	½	+	½	+	½	−	1.33	
Apr. 2	½	+	½	+	......	......	2 +	
Do	½	+	½	+	½	−	1.33	
Fort Foote:								
Mar. 19	1	+	1	+	1	+	1 +	
Mar. 20	½	+	½	+	½	−	1.33	
Mar. 23	½	+	½	+	½	−	1.33	
Mar. 25	½	+	½	+	½	+	2 +	
Mar. 30	½	+	½	+	½	+	2 +	1.5
Mar. 31	½	+	½	−	½	−	.66	
Apr. 2	½	+	½	+	......	......	2 +	
Apr. 3	½	+	½	+	½	−	1.33	
Giesboro Point:								
Mar. 19	1	+	1	+	1	+	1 +	
Mar. 20	½	+	½	−	½	−	.66	
Mar. 23	½	+	½	+	½	+	1.33	
Mar. 25	½	+	½	−	½	−	.66	
Mar. 30	½	+	½	+	½	−	1.33	.8
Mar. 31	½	−	½	−	½	−	.66−	
Apr. 2	½	+	½	−	½	......	1	
Apr. 3	½	+	½	−	½	−	.66	
Red buoy above Anacostia River:								
Mar. 19	1	+	1	−	1	−	.66	
Mar. 20	½	+	½	+	½	+	2 +	
Mar. 23	½	+	½	+	½	+	2 +	
Mar. 25	½	+	½	+	½	+	2 +	1.4
Mar. 30	½	+	½	+	½	−	1.33	
Mar. 31	½	+	½	−	½	−	.66	
Apr. 2	½	+	½	−	......	......	1	
Apr. 3	½	+	½	+	½	−	1.33	

TABLE 16.—*Results of tests for lactose-fermenting, spore-forming anaerobes, 1915*—Continued.

Place and date.	Cubic centimeters tested.	Gas.	Cubic centimeters tested.	Gas.	Cubic centimeters tested.	Gas.	Average number per cubic centimeter.	Station average.
Red buoy above railroad bridge:								
Mar. 19	1	+	1	+	1	−	0.66	
Mar. 20	½	+	½	+	½	+	2 +	
Mar. 23	½	+	½	+	½	−	1.33	
Mar. 25	½	+	½	+	½	−	1.33	1.3
Mar. 30	½	+	½	+	½	−	1.33	
Mar. 31	½	+	½	+	½	−	1.33	
Apr. 2	½	+	½	−	......	......	1	
Apr. 3	½	+	½	+	½	−	1.33	
Seventeenth and D Streets:								
Mar. 19	1	+	1	+	1	+	1 +	
Mar. 20	½	+	½	−	½	−	.66	
Mar. 23	½	+	½	+	½	−	1.33	
Mar. 25	½	+	½	+	½	−	1.33	1.1
Mar. 30	½	+	½	+	½	−	1.33	
Mar. 31	½	+	½	+	½	−	1.33	
Apr. 2	½	+	½	−	......	......	1	
Apr. 3	½	+	½	−	½	−	.66	
Three Sisters:								
Mar. 19	1	+	1	+	1	−	.66	
Mar. 23	½	+	½	+	½	+	2 +	
Mar. 25	½	+	½	+	½	−	1.33	
Mar. 30	½	+	½	+	½	−	1.33	1
Mar. 31	½	+	½	−	½	−	.66	
Apr. 2	½	+	½	−	......	......	1	
Apr. 3	½	+	½	+	½	+	1.33	
Rock Creek at mouth:								
Mar. 19 U	1	+	1	+	1	+	1 +	1 +
Mar. 19 V	1	+	1	+	1	+	1 +	
Rock Creek above Chevy Chase Branch:								
May 8	1	+	1	+	1	+	1 +	....
Rock Creek below Chevy Chase Branch:								
May 8	1	+	1	+	1	+	1 +	....
Rock Creek north end Rock Creek Park:								
May 8	1	−	1	+	1	+	1 +	....
Chevy Chase Branch at Rock Creek:								
May 8	1	+	1	+	1	+	1 +	....
Falls Branch at Wisconsin Avenue:								
May 8	1	+	1	+	1	+	1 +	....
Anacostia River at Bennings Branch:								
May 8	1	+	1	+	1	+	1	....
Potomac at Harpers Ferry:								
May 5	5	+	3	+	2	+	.5 +	
Do	5	+	3	+	2	−	.5 −	
May 6	5	+	3	−	2	−	.3 −	.5
Do	5	+	3	+	2	+	.5 +	
Do	5	+	3	+	2	+	.5 +	
Do	5	+	3	+	2	−	.5 −	
Shenandoah at Harpers Ferry:								
May 5	5	+	3	+	2	+	.5 +	
Do	5	+	3	+	2	+	.5 +	
Do	5	+	3	+	2	−	.5 −	
May 6	5	+	3	−	2	−	.3 −	.5
Do	5	+	3	−	2	−	.3 −	
Do	5	+	3	+	2	+	.5 +	
Do	5	+	3	+	2	+	.5 +	
Canal at Harpers Ferry:								
May 5	5	+	3	−	2	−	.5 −	.4
Potomac at Bridge below Magnolia:								
May 6	5	+	3	+	2	−	.5 −	.5
Potomac, bridge at Magnolia:								
May 4	5	+	3	+	2	−	.5 −	....
Potomac, bridge above Magnolia:								
May 4	5	+	3	+	2	+	.5 +	....
Little Cacapon Creek:								
May 4	5	+	3	+	2	+	.5 +	....
South Branch of Potomac above North Branch:								
May 4	5	+	3	−	2	+	.5	....

TABLE 16.—*Results of tests for lactose-fermenting, spore-forming anaerobes, 1915*—Continued.

Place and date.	Cubic centimeters tested.	Gas.	Cubic centimeters tested.	Gas.	Cubic centimeters tested.	Gas.	Average number per cubic centimeter.	Station average.
North Branch of Potomac above South Branch:								
May 4	5	+	3	+	2	+	0.5 +	....
Potomac below Piedmont:								
Apr. 11	1	+	1	–	1	–	.33	0.33
Potomac above pulp mill at Luke:								
Apr. 11	1	–	1	–	1	–	.33–	....
Georges Creek above bridge at Potomac:								
Apr. 11	1	+	1	+	1	–	.66	.66
SEWAGE.								
Mar. 19	0.1	+	0.1	+	0.1	+	10+	55
Mar. 20	.05	+	.05	+	.05	+	20+	....
Do	.05	+	.05	+	.05	+	20+	....
Mar. 24	.05	+	.05	+	.05	+	20+	....
Do	.05	+	.05	+	.05	+	20+	....
Mar. 25	.05	+	.05	+	.05	+	20+	....
Do	.05	+	.05	+	.05	+	20+	....
Mar. 28	.01	+	.01	+	.01	+	100+	....
Do	.01	+	.01	+	.01	+	100+	....
Mar. 30	.01	+	.01	+	.01	+	100+	....
Do	.01	+	.01	+	.01	+	100+	....
Mar. 31	.01	+	.01	+	.01	+	100+	....
Do	.01	+	.01	+	.01	–	66+	....
Apr. 2	.01	+	.01	+	.01	–	66	....
May 8	.001	–	.001	–	.001	–	100	....
Do	.001	–	.001	–	.001	–	100+	....
CANAL MUD, CUMBERLAND.								
Apr. 22	0.0001	+	0.0001	+	0.0001	+	100000	500000
Apr. 27	.00001	+	.00001	+	.00001	–	1000000	....
LAKE GORDON WATER.								
Apr. 23	10	+	1	+	1	–	1	1
May 7	10	+	1	+	.1	–	1	....

Altogether nearly 150 samples were collected from about 40 sources and 3 or more tubes made on each sample. These sources range from sewage and mud to water with varying degrees of pollution, including filtered and treated water. The number of spores in the river water determined by this method is remarkably constant. Unlike *B. coli*, which varies many thousand per cent, from several hundred per c. c. to less than 1 in 10 c. c., according to the intensity of pollution, these spores were found often in the best river water in 10 c. c. and seldom showed an average much above 4 or 5 per c. c. The averages at stations between Lower Cedar Point and Washington, representing water exceedingly pure and water highly polluted, are plotted in Charts E and F, and they show comparatively little difference. Their number furnishes no clue in this case to the degree of pollution and purification, as does the number of *B. coli*.

The results from other parts of the river are of a similar nature. Spores of gas-forming organisms are found in from 1 to 5 c. c. of water taken at points extending almost to the headwaters of the Potomac. Lake Gordon, formed by damming Evitts Creek, which flows through a comparatively uninhabited watershed, shows these organisms ordinarily in 1 c. c. This lake is used as the water suoply of Cumberland, and even after treatment with hypochlorite and filtering the water still contains these organisms in 10 c. c. It would seem from these tests, which cover a large territory and consistently show these spores in from 1 c. c. to 10 c. c., and do not vary with the condition of the water to any considerable extent, that their significance can not be the same as *B. coli.*

The generally uniform distribution of organisms of this group in surface waters, even in those not highly contaminated with sewage and with no considerable increase in polluted waters, indicates that this group is not, as has sometimes been supposed, an organism characteristic of the intestine. Though found in proportion similar to that of the hay-bacillus group in feces, this means, probably, as in the latter case, that it may grow there as well as in other places. It is an organism similar to *B. subtilis* in many respects, except that it is anaerobic. Indeed, certain members of the group are known to live in large numbers in soil. It appears likely, therefore, that it can develop in any oxygen-free material rich in organic matter. Tests on sewage show the spores to the number of less than 100 per c. c.—a thousand fold fewer than the number of the characteristic form *B. coli.* Tests on the digested sewage sludge, constituting the mud at the head basins of the Chesapeake & Ohio Canal, on the other hand, show about 500,000 per c. c. The rich putrefying mud in this case seems to furnish a natural habitat for their growth. These organisms are also found in mud from oyster beds on the ocean side of Fishermans Island, Va.

These observations are in complete accord with work reported elsewhere. Houston, in England, accurately described the same phenomena; Savage summarizes a large number of results by different workers demonstrating the general distribution of the anaerobic spore-forming group. Besides being found in feces, sewage, and water, it has been isolated from foodstuffs, such as wheat, oats, rice, oatmeal, and wheat flour, milk, grains and seeds, salted cod, canned foods, oysters, as well as from road dust, etc. Savage says:

> The evidence available shows that it is absent, or relatively absent, from sources which have never been contaminated, but that it is fairly prevalent in sources the pollution of which had taken place even at a long antecedent period.

The important bearing of these facts on the presumptive test must be apparent. A fairly small uniform distribution of the spores in a water receiving large amounts of sewage and subsequently purify-

ing itself would give just the effect shown on Chart E. Where the number of *B. coli* is large compared with the anaerobes the latter are lost in the high dilutions necessary to determine the gas formers present, consequently all the tubes show *B. coli* and the presumptive test is efficient. Where the number of *B. coli* diminishes, but the spores persist, the proportions become more nearly the same, and the gas which some of the tubes show is due to anaerobes which will not grow on an aerobic endoplate. Just at those places where the water seems to be on the border between a good and doubtful water the presumptive test fails, for the spores alone indicate merely remote pollution. This effect has been very strikingly shown in the report of the International Joint Commission on the Pollution of Boundary Waters, where large areas of lake water have been polluted locally and most of the *B. coli* have died out. (Table 17.)

The increasing use of hypochlorite for disinfecting water supplies has brought up the same question. Waters which previous to disinfection show *B. coli* consistently in small amounts, also show gas in 1 c. c. to 10 c. c. after disinfection. It is relatively easy to kill the *B. coli* in the water, but to kill the spores would require an excessive amount of chlorine. The organisms have been reported from water at Grand Forks, N. Dak., after treatment, at Cumberland, Md., at Baltimore, Md., and undoubtedly have been noticed in many other places where hypochlorite is used.

TABLE 17.—*Gas producers, St. Johns River.*[1]

Sampling point No.	Number of samples taken.	Average per 100 c. c. by Phelps method.			Sampling point No.	Number of samples taken.	Average per 100 c. c. by Phelps method.		
		Total gas producers.	Typical B. coli.	Anaerobic gas producers.			Total gas producers.	Typical B. coli.	Anaerobic gas producers.
1	21	467	65	402	17	21	476	31	445
2	21	647	160	487	18	21	480	117	363
3	21	566	70	496	19	21	467	117	350
4	20	472	167	305	20	21	600	155	445
5	21	536	160	376	21	21	520	103	417
6	21	643	112	531	22	21	566	112	454
7	21	515	155	360	23	21	1,086	725	361
8	21	730	250	480	24	21	695	202	493
9	21	433	18	415	25	21	614	112	502
10	21	433	112	321	26	21	601	117	484
11	21	519	57	462	27	21	524	57	467
12	21	600	61	539	28	20	540	254	286
13	21	519	74	445	29	21	1,090	631	359
14	21	561	103	458	30	20	476	112	364
15	21	566	164	402	31	21	480	112	364
16	21	604	155	449	32	21	528	70	458

[1] Progress Report of the International Joint Commission in re The Pollution of Boundary Waters.

The following table by George T. Palmer, taken from the report on the water supply of Trenton, N. J., indicates the same condition after treatment, where only the presumptive test was used.

Sample.	River.		Reservoir.			
			Inlet.		Outlet.	
	Number of tubes.	Per cent positive.	Number of tubes.	Per cent positive	Number of tubes.	Per cent positive.
c. c.						
0.01	60	13	....	....	....	....
0.1	64	61	5	0	5	20
1.0	64	98	33	3	27	11
5.0	....	....	125	33	117	22
10.0	....	....	5	60	5	80

TABLE 18.

In his investigation of drinking waters on trains Dr. Creel, of this service, found a large percentage of the waters containing this organism in 1 c. c. to 10 c. c. and *B. coli* absent. Probably this is due to trains receiving water at towns using hypochlorite in their supplies. Dr. Creel made a rather intensive study of these organisms.

Although the presumptive test may be allowable where the pollution is considerable and the number of *B. coli* is large, there are many places where it would give very erroneous results. In the examination of oysters and the water over the beds, where the pollution is remote and where the standards of purity are very rigid, the conditions are just such as to obtain a large number of positive presumptive tests, although colon bacilli are comparatively few. Savage quotes a case where, of 65 samples of shellfish, 15 showed *B. enteritidis sporogenes*, while *B. coli* was present in only two samples. Similar results were obtained in the present investigation, where in 665 sets of tubes, made from oysters from polluted and clean sources, the average number of *B. coli* was less than 60 per cent of the total number of gas formers.

Conclusions: 1. The reliability of the lactose-broth and lactose-bile presumptive test varies directly with the degree of pollution, therefore inversely with the remoteness in time and distance from the source of pollution. This is due to the general occurrence of a group of organisms in small and almost constant numbers (approximating 1 per c. c.), which are not manifest when the number of *B. coli* is large, but appear evident when the number of *B. coli* approaches or is less than 1 per c. c.

2. These organisms are of the group of spore-forming, lactose-fermenting anaerobes, and are thus eliminated by the aerobic endoplate.

Observations on the relative merits of lactose bile and lactose broth.—Many workers have advocated the use of lactose bile as a medium for the isolation of sewage-gas formers, and the 1912 committee on standard methods of water analysis of the American Public

Health Association recommended its use. It is claimed that it is unnecessary in an extensive study to confirm the results of the lactose bile fermentation test, as only the sewage forms, *B. coli* or *B. welchii*, ferment the medium. It has been stated, furthermore, that the number of tubes showing gas closely compares with the number of *B. coli*, as determined by enrichment in lactose broth, and subsequently confirmed by the laborious methods of subculture tests. Thus a great deal of labor would be saved by using lactose bile as a presumptive test instead of following the old procedure, although by using endoplates alone for confirmation the saving in work is not considerable.

It was thought advisable in this investigation to run a duplicate set of tests, using both media side by side, thus making an exact comparison of the reliability of the lactose-bile tubes and the plain lactose-broth tubes, both with and without the endoplate and further confirmation.

In all 1,851 parallel sets of broth and bile tubes were recorded, 1,148 of which were made from the river water from various points, 38 from fresh sewage, and 665 from oysters. The results of these tests are summarized in Table 11, where are given the number of samples, the percentage positive in the various dilutions, the number of organisms per c. c. calculated by Phelps's method with broth and bile, both presumptive and confirmed, and the percentage confirmed in each .

TABLE 19.—*Results obtained from 1,851 samples planted in both lactose broth and lactose bile.*

	Percentage of samples containing B. coli in—									
	10 c. c.		1 c. c.		0.1 c. c.		0.01 c. c.		0.001 c. c.	
	Broth.	Bile.	Broth.	Bile.	Broth.	Bile.	Broth.	Bile.	Broth.	Bile.
Above Giesboro Point	....	......	....	....	86.8	77.4	49.0	34.0	7.5	7.5
Giesboro Point	....	......	....	....	100.0	86.4	76.2	49.1	20.3	8.5
Fort Foote	....	......	....	....	93.5	96.8	82.0	75.0	23.0	6.6
Fort Washington	....	......	....	....	96.6	98.4	80.0	63.3	26.7	6.7
Whitestone Point	....	......	....	....	94.3	98.6	72.8	64.2	15.7	7.1
Indianhead	....	......	94.2	94.4	92.2	90.0	65.8	48.9	11.1	10.0
Possum Point	89.7	89.7	88.8	88.8	71.0	71.0	33.6	13.1	2.8	.9
Maryland Point	76.2	67.4	56.5	44.9	15.6	6.8	2.0	.7	....	....
Popes Creek	60.4	45.6	27.1	12.0	4.4	1.2	....	....	....	....
Lower Cedar Point	60.6	42.9	22.5	9.9	....	....	....	....	....	....
Below Lower Cedar Point	33.7	21.9	11.1	4.8	.7	.4	....	....	....	....
Total above Maryland Point	94.4	92.0	93.2	92.0	89.0	87.2	63.0	46.2	14.0	6.4
Total below Possum Point	52.9	40.3	26.5	16.3	5.0	2.0	.5	.2	....	....
Grand total	92.9	82.6	73.3	64.8	54.8	51.6	36.5	26.6	8.0	3.7
	0.0001 c. c.		0.00001 c. c.		0.000001 c. c.					
Sewage	94.7	76.3	44.7	18.4	5.3	0.0	....	....	....	....
			1 c. c.		0.1 c. c.					
Oysters	....	......	20.9	18.3	7.2	5.6	....	....	....	....

TABLE 19.—*Results obtained from 1,851 samples planted in both lactose broth and lactose bile*—Continued.

	B. coli per c. c.				Percentage confirmed.		Number of samples.
	Broth presumptive.	Broth confirmed.	Bile presumptive.	Bile confirmed.	Broth.	Bile.	
Above Giesboro Point	128	120	114	106	94.0	92.7	53
Giesboro Point	202	202	134	129	100.0	96.2	59
Fort Foote	305	290	138	133	95.0	96.7	61
Fort Washington	336	325	129	127	96.7	98.3	60
Whitestone Point	229	216	133	131	94.3	98.6	70
Indianhead	178	168	146	143	94.5	97.7	90
Possum Point	69.6	63	28	27	90.5	98.0	107
Maryland Point	5.2	4	2.6	2	76.2	81.8	148
Popes Creek	1.10	.72	.23	.16	65.3	69.9	159
Lower Cedar Point	.38	.27	.20	.14	70.5	71.4	71
Below Lower Cedar Point	.42	.19	.17	.11	45.4	64.8	270
Total above Maryland Point	206	192	111	108	93.2	97.3	500
Total below Possum Point	2.0	1.2	.77	.56	61.5	72.8	648
Grand total	119	84	54	47	70.3	86.8	1,148
Sewage	....	97,400	....	24,200	100.0	96.7	38
Oysters	1.61	.93	1.20	.74	57.7	61.6	665

It may be observed that throughout the lactose broth gave higher results, confirmed as well as presumptive, than lactose bile. The percentage of positive lactose-bile tubes confirmed on endomedia is consistently greater than on lactose broth, but had they all been confirmed they would neither have given as high a result as the confirmed tubes on lactose broth, nor would they generally have given as near the true figure as the presumptive lactose-broth tubes. Chart E presents these results graphically and shows convincingly that for the Potomac River water, at least, lactose broth is a more reliable medium for the presumptive test than lactose bile, except at the lower-river stations, remote from pollution, where the bile presumptive test is more reliable.

The latter result is rather surprising, since it has been claimed that the bile presumptive test gives close to the actual number of *B. coli* where the pollution is fresh, but fails to give all the forms where the pollution is remote, because some are weakened and can not ferment bile, according to the last report of the American Public Health Association on "Standard Methods of Water Analysis" (1912, p. 88):

> In tests on sewage and contaminated waters, however, the lactose bile has been proven to give positive results in higher dilutions than any other medium.

The above statement is not in accord with the results obtained in this investigation of conditions existing in the Potomac River water or Washington sewage, for the lactose broth consistently gave positive results in higher dilutions than lactose bile; and when the presumptive bile test alone was used, as recommended, the results corre-

sponded more closely with the actual number of *B. coli* present in the relatively clean lower-river water than it did where the river was freshly polluted. The lactose broth presumptive test would have given nearer the actual number of *B. coli* where the river was freshly polluted, while the bile presumptive test would have given closer results where it was distant from pollution.

The report on standard methods furthermore states (p. 87): "Attenuated *B. coli* does not represent recent contamination, and all *B. coli* not attenuated grows readily in lactose bile." The results on sewage seem to contradict this, since lactose bile only yielded 25 per cent of the number of *B. coli* calculated from lactose broth, while in the river the bile gave from 50 to 70 per cent as many *B. coli* as the broth. Jordan, of Chicago, has published similar results (Fifteenth International Congress of Hygiene, Transactions, vol. 2, parts 1, 2, pp. 48), proving conclusively that freshly isolated strains of *B. coli* were inhibited to as great or greater degree than older strains. It would seem, therefore, that the advantage of lactose bile over lactose broth is more apparent than real.

The disadvantages of lactose broth as a presumptive test, as an index of river pollution, are thus shared by the lactose bile. The curves of each on Chart E are strikingly similar, except that the bile curve falls short of the lactose-broth curve at all points. The curves showing the percentage of fermentation tubes confirmed on endo reveal the failure of the presumptive test. Where the river is highly polluted, both give results comparing closely with the confirmed endoplates. Where the river begins to purify itself and the number of *B. coli* diminish, there the reliability of the presumptive test also fails. As has been aptly said, "the presumptive test is reliable when *B. coli* is present."

Considering, therefore, the failure of the presumptive test alone, it is evident that some check must be imposed upon it. Longley and Baton, working at the Washington, D. C., filtration plant with Potomac River water and with dextrose, both state: "The best presumptive test we could use for the conditions in this laboratory would be the preliminary fermentation tube followed by the litmus lactose agar-agar plate." (Journal of Infectious Dis., vol. 4, p. 411.)

What is here said of the litmus lactose agar is even truer of the endo plate, for heavier transfers may be made and the appearance of *B. typhosus* and *B. coli* on endo is very characteristic. By this one additional step the efficiency of the "presumptive test" may be made nearly 100 per cent.

W. H. Frost, working in the hygienic laboratory in 1909, found the efficiency of endo medium to be about 96 per cent. (Hygienic Laboratory Bull. 78, pp. 73 to 134.)

Since it is necessary to go one step beyond the fermentation tube, there is every advantage to be gained by using an enrichment medium which will give the largest number of *B. coli* to start with. The lactose broth is preferable for this purpose and diminishes the time necessary for the test. For these reasons the technique described elsewhere was adopted in the isolation of *B. coli*.

From a consideration of the evidence presented concerning the influence of the anaerobes described, the comparative merits of broth and bile media and the status of the presumptive test, it is believed that the following conclusions may be derived:

1. The reliability of the lactose-broth and lactose-bile presumptive test varies directly with the degree of the pollution, and inversely with the remoteness in time and distance from the source of the pollution.

2. This is due to the general occurrence of a group of spore-forming, lactose-fermenting, anaerobic organisms, in small but almost constant numbers (approximating 1 per c. c.), which are not sufficient to become manifest when the number of *B. coli* is large, but become evident when the latter is reduced to about 1 per c. c. or less. These anaerobes are eliminated by the aerobic endo plate.

3. The anaerobes may be separated from nonspore-bearing organisms, such as *B. coli*, by heating the water to 70° for 10 minutes and inoculating into freshly sterilized lactose-broth tubes.

4. The anaerobes resist ordinary hypochlorite disinfection of water, and may be recovered from waters so treated.

5. They persist for long periods of time and are therefore found in remotely polluted surface waters and oyster beds. Hence, the results obtained by the use of the presumptive tests alone under such conditions are erroneous, especially in the examination of oyster beds remote from pollution.

6. They seem to be almost universally distributed in decomposing organic matter, and this, together with their much greater resistance, gives their presence a significance different from that of *B. coli*.

Observations on endo medium as a means of confirming B. coli.—In this investigation the classification of organisms of sewage origin, suggested by Jackson and adopted by the American Public Health Association in 1912, has been followed. Endo agar plates, in conjunction with the enrichment fermentation tubes, have been used throughout and the results computed on this basis. In confirming presence of the *B. coli* group, the endo medium, originally introduced as a means of isolating *B. typhosus*, was found admirably efficient. The striking appearance of the *B. coli* group renders them unmistakable; moreover, because of the selective action of the medium, large transfers are possible and particularly advantageous where the

number of *B. coli* present in the enrichment tube is relatively small. Depending, as does this method, upon a surface growth, the transparency of the medium is not important, hence tedious and difficult clarification methods are unnecessary.

Lactose broth, lactose peptone bile, and litmus lactose agar were prepared according to the standard methods adopted by the American Public Health Association. For the endo agar certain modifications, adopted by the hygienic laboratory, simplify the preparation as follows: To 1,000 c. c. of water are added sodium chloride 5 gm., Leibig's beef extract 10 gm., Witte's peptone 10 gm.; solution is effected by heat, and, after cooling, 30 gm. powdered agar are sprinkled on the surface of the solution and allowed to dissolve without stirring. Sufficient 10 per cent solution of anhydrous sodium carbonate is added to make the medium slightly alkaline to litmus. A very clear medium may be obtained by allowing the agar to settle and harden in some vessel from which it may be turned out en masse. The bottom layer, containing practically all of the sediment, may be cut off with a knife, the agar then remelted and stored in 200 c. c. lots in long-necked Erlenmeyer or Florence flasks of 250 c. c. capacity. The medium is allowed to remain in an Arnold sterilizer at 100° for three hours.

A further simplification of the process may be effected by the preparation of a stock solution of such strength that 10 c. c. shall contain lactose 2 gm., sulphite 5 gm., in distilled water, with 1 c. c. of a 10 per cent solution of basic fuchsin in 96 per cent alcohol. By keeping the lactose crystals suspended near the top of the water, convection currents cause it to melt very rapidly, and it is not necessary to reduce the crystals to powder. When plates are needed, 10 c. c. of this stock solution are added to each 200 c. c. of liquefied agar, the flask agitated gently to diffuse the solution without foaming, and the plates poured. The Petri dishes are allowed to stand with the tops off in a dark, dust-free room for 20 to 30 minutes. Plates not immediately needed may be stored for several days in a refrigerator room.

The stability of this stock solution having been questioned, a quantity made July 8 and set aside was later compared with solutions made July 20, August 7, and August 24, with the following results:

TABLE 20.—*Number of positive results obtained.*

Solutions made	July 8.	July 20.	Aug. 7.	Aug. 24.
Fresh-stock solution	22	13	18	12
Old-stock solutions	22	13	15	10
Percentage of efficiency that old solution bears to new solutions	100%	100%	83%	83%

As the table shows, the old solution retained 100 per cent of its efficiency for at least two weeks and lost 17 per cent of its efficiency after 30 days. The results therefore justify the conclusion that the solution may safely be used for at least two weeks.

For confirmation of characteristic colonies typical colonies of the *B. coli* group were fished from endo plates made during the routine examinations of river water and transferred to agar slants. From the same tubes from which the endo plates had been smeared litmus lactose agar plates were made according to the following procedure: A platinum needle was dipped into the tube and washed off in a tube containing 5 c. c. of sterile water. Two loops of this suspension were transferred to a tube of litmus lactose agar, and from this tube another loopful was put into a second litmus lactose agar tube. Both of the tubes were poured into Petri dishes and incubated for 24 hours at 37°, after which they were examined for typical growths which were transferred to agar slants. The cultures so obtained were incubated, and, if found to be pure, transferred to the following media: Peptone solution, nitrate solution, litmus milk, mannite, saccharose, raffinose, and dulcite broths.

Determination of motility was also made as soon after isolation as was practicable. Gelatin stabs were inoculated with small portions of the pure cultures and incubated at 20° for 14 days, being examined daily for evidence of liquefaction.

The various subculture procedures were those recommended by the Report on Standard Methods of the American Public Health Association.

During the routine examination of the samples taken throughout the investigation 210 pure cultures were studied, representing all phases of the work. These cultures were isolated from tubes which had shown lactose fermentation and had given a positive metallic sheen on endo agar plates, or had shown the characteristic red colonies on lactose litmus agar.

Table 21 presents a complete and detailed tabulation of all the results obtained by the methods described. The abbreviations used under "Action on milk," indicate the following: a=acid reaction; c=coagulation; r=reduction of litmus; g=such gas formation in the tube as to have been evident. As it is shown by the column "Fermentation medium" all of the samples were taken from tubes which had shown fermentation of lactose in either broth or bile. Motility is expressed by +, the degree of motility not having been noted. The + sign under mannite, saccharose, dulcite, and raffinose indicates the formation of gas.

TABLE 21.—*Results of confirmatory tests upon 210 lactose-splitting gas-forming organisms.*

No.	Date.	Sample obtained from—	Depth.	Fermentation medium.	Per cent gas.	Medium used for isolation.	Motility.	Action on milk.	Indol.	Reduction of nitrates.	Action on gelatin.	Mannite.	Saccharose.	Dulcite.	Raffinose.
	1913.		*Feet.*												
1	Dec. 4	Maryland Point, middle channel.	2	Lactose broth.	30	Endo agar	+	a-c-r	+	+	–	+	–	+	–
2	...do	.....do	2	Lactose bile	25	.....do	+	a-c-r	+	+	–	+	+	+	+
3	...do	Possum Point, Virginia side.	2	.....do	95	.....do	+	a-c	Trace.	+	–	+	+	–	–
4	...do	Possum Point, Virginia side channel.	20	.....do	75	Endo	+	a-c	+	+	–	+	+	–	–
5	...do	Possum Point, Maryland side channel.	20	Lactose broth.	25	.....do	+	a-c-r	+	+	–	+	+	+	+
6	...do	Indian Head, Maryland side.	2	.....do	95	.....do	+	a-c-r	+	+	–	+	–	+	–
7	...do	Indian Head, Maryland side channel.	20	Lactose bile	30	.....do	+	a-c-r	+	+	–	+	+	–	–
8	...do	Indian Head, Virginia side channel.	20	Lactose broth.	50	.....do	+	a-c-r	+	+	–	+	+	+	+
9	...do	Whitestone Point channel	20	.....do	95	.....do	+	a-c-r	+	+	–	+	+	–	–
10	...do	Fort Washington channel	20	.....do	20	.....do	+	a-c-r	+	+	–	+	+	+	+
11	...do	Fort Foote channel	2	.....do	35	.....do	+	a-c-r	–	+	–	+	+	+	+
12	...do	.....do	20	.....do	50	.....do	–	a-c-r	+	+	–	+	+	–	+
13	...do	Seventeenth and D Streets	2	.....do	20	.....do	+	a-c-r	+	+	–	+	+	+	+
14	Dec. 5	Marshall Hall channel	18	.....do	25	Litmus lactose agar	+	a-c-r	+	+	–	+	+	+	+
15	...do	Fort Foote channel	25	.....do	20	.....do	+	a-c-r	+	+	–	+	+	+	+
16	...do	Giesboro Point, Maryland side.	2	.....do	2	.....do	+	a-c	–	+	–	+	+	–	+
17	...do	Giesboro Point channel	25	.....do	20	.....do	+	a-c	+	+	–	+	–	+	–
18	...do	Giesboro Point, Virginia side.	2	.....do	20	.....do	–	a-c-r	+	+	–	+	+	–	+
19	...do	Railroad bridge	2	.....do	25	.....do	+	a-c-r	+	+	–	+	+	–	–
20	...do	Sewage Pumping station	....	.....do	20	.....do	–	a-c-r-g	+	+	–	+	+	–	+
21	Dec. 8	Possum Point channel	18	.....do	20	.....do	+	a-c-r	Trace.	+	–	+	+	–	–
22	...do	Indianhead, Maryland side	2	.....do	20	.....do	+	a-c-r	+	+	–	+	+	+	+
23	...do	Indianhead channel	20	.....do	25	.....do	+	a-c-r	+	+	–	+	+	+	+
24	...do	Whitestone Point channel	2	.....do	15	.....do	+	a-c	Trace.	+	–	–	+	+	+
25	...do	.....do	2	.....do	15	Endo	+	a-c-r	+	+	–	+	+	+	+
26	...do	Fort Washington channel	2	.....do	15	.....do	+	a-c-r	+	+	–	+	+	+	+
27	...do	.....do	20	.....do	30	.....do	+	a-c-r	Trace.	+	–	+	+	+	+
28	...do	Fort Foote channel	2	.....do	20	.....do	+	a-c-r	+	+	–	+	+	+	+
29	...do	Fort Foote, Virginia side	2	.....do	25	.....do	–	a-c-r	+	+	–	+	+	–	+
30	...do	Giesboro Point, Maryland side.	2	.....do	55	.....do	+	a-c-r	+	+	–	+	+	+	+
31	...do	Giesboro Point channel	2	.....do	50	.....do	+	a-c	+	+	–	+	+	+	+
32	...do	Indianhead channel	20	.....do	25	.....do	+	a-c	+	+	–	+	–	+	–

33	...do...	Giesboro Point, Virginia side.	2	.....do	25	.....do	+	a-c	+	Slight.	−	+	+	+	+
34	...do...	Muddy Possum Point channel.	18	.....do	35	.....do	+	a-c	+	+	−	+	+	+	−
35	...do...	Muddy Fort Washington channel.	22	.....do	15	.....do	+	a-c-g	+	+	−	+	+	−	−
36	...do...	Sewage Pumping Station		.....do	95	.....do	+	a-c-g	+	+	−	+	+	−	−
37	...do...	.....do		Lactose bile	50	.....do	+	a-c-g	+	+	−	+	+	−	−
38	...do...	Marshall Hall channel	2	.....do	25	.....do	−	a-c	+	+	−	+	+	−	+
39	...do...	Fort Foote, Maryland side	2	.....do	10	.....do	+	a-c-r	+	+	−	+	+	+	+
40	Dec. 9	Giesboro Point, Maryland side.	2	.....do	40	.....do	+	a-c	+	+	−	+	−	−	−
41	...do...	Seventeenth and D Streets channel.	2	.....do	50	.....do	+	a-c-g	+	Slight.	−	+	+	−	−
42	...do...	Giesboro Point, Virginia side.	2	.....do	5	.....do	+	a-c	−	+	−	+	+	−	+
43	...do...	Fort Foote, Maryland side	2	.....do	50	.....do	+	a-c	+	+	−	+	−	−	+
44	...do...	Fort Washington, Virginia side.	2	.....do	35	.....do	+	a-c	+	+	−	+	−	−	−
45	...do...	Fort Washington channel	2	.....do	15	.....do	+	a-c	Trace.	+	−	+	+	−	−
46	...do...	Whitestone Point, Maryland side.	2	.....do	45	.....do	+	a-c-g	+	+	−	+	−	+	−
47	...do...	Whitestone Point channel	2	.....do	40	.....do	−	a-c-g	+	+	−	+	+	−	+
48	...do...	Rock Creek	2	.....do	25	.....do	+	a-c-g	+	+	−	+	−	−	+
49	...do...	Sewage Pumping Station		.....do	25	.....do	+	a-c-g	+	+	−	+	−	−	−
50	Dec. 10	.....do		.....do	25	.....do	+	a-c	+	+	−	+	−	−	−
51	...do...	.....do		.....do	20	.....do	+	a-c-g	+	+	−	+	−	−	+
52	...do...	Whitestone point channel	15	Lactose broth.	5	.....do	+	a-c	Trace.	+	−	+	−	+	−
53	...do...	Whitestone Point, Virginia side.	2	.....do	40	.....do	+	a-c-g	+	+	−	+	+	+	+
54	...do...	Indianhead, Maryland side channel.	2	.....do	14	.....do	+	a-c-r	+	+	−	+	+	+	+
55	...do...	.....do	15	.....do	40	.....do	+	a-c	+	+	−	+	+	+	+
56	...do...	Indianhead, Virginia side channel.	2	.....do	50	.....do	+	a-c-g	+	+	−	+	+	+	+
57	...do...	Indianhead, Virginia side	2	.....do	50	.....do	+	a-c-g-r	+	+	−	−	+	−	−
58	...do...	Possum Point, Maryland side.	2	.....do	50	.....do	+	a-c-g	−	+	−	+	+	−	+
59	...do...	Indianhead, Maryland side channel.	2	Lactose bile	50	.....do	+	a-c	+	+	−	+	−	−	−
60	...do...	.....do	15	.....do	60	.....do	−	a-c-g	+	+	−	+	+	−	+
61	...do...	Indianhead, Virginia side	15	.....do	70	.....do	+	a-c-g	+	+	−	+	+	+	+
62	...do...	.....do	2	.....do	10	.....do	+	a-c	+	+	−	+	+	+	+
63	...do...	Possum Point, Maryland side	2	.....do	50	.....do	+	a-c-g	+	+	−	+	−	−	−
64	...do...	Possum Point, Maryland side channel.	2	.....do	75	.....do	+	a-c	+	+	−	+	+	−	−
65	...do...	.....do	15	.....do	75	.....do	+	a-c-r	+	+	−	+	+	+	+
66	...do...	Possum Point, Virginia side channel.	15	.....do	60	.....do	+	a-c-r	+	+	−	+	+	+	+
67	...do...	Possum Point, Virginia side.	2	.....do	75	.....do	+	a-c-r-g	+	+	−	+	+	+	+
68	Dec. 11	Sewage Pumping Station		Lactose broth.	30	.....do	+	a-c-g	Trace.	+	−	+	−	+	+
69	...do...	.....do		Lactose bile	10	.....do	−	a-c-r-g	+	+	−	+	+	−	+
70	Dec. 10	Indianhead, Virginia side channel.	15	Lactose broth.	20	.....do	+	Slight acidity.	−	+	−	+	+	+	+

TABLE 21.—*Results of confirmatory tests upon 210 lactose-splitting gas-forming organisms*—Continued.

No.	Date.	Sample obtained from—	Depth.	Fermentation medium.	Per cent gas.	Medium used for isolation.	Motility.	Action on milk.	Indol.	Reduction of nitrates.	Action on gelatin.	Mannite.	Saccharose.	Dulcite.	Raffinose.
	1913.		*Feet.*												
71	Dec. 15	Seventeenth and D Streets channel.	2	Lactose broth.	10	Endo	+	a-c-r-g	+	+	−	+	+	+	+
72	...do	...do	2	Lactose bile	60	...do	+	a-c-r	+	+	−	+	+	−	−
73	...do	Railroad bridge	2	...do	70	...do	+	a-c	+	+	−	+	−	+	−
74	...do	Giesboro Point, Virginia side.	2	Lactose broth.	35	...do	+	a-c-g	+	+	−	+	+	+	+
75	...do	Giesboro Point channel	2	...do	20	...do	+	a-c-r	−	+	−	+	+	−	+
76	...do	...do	2	Lactose bile	60	...do	+	a-c-g	+	+	−	+	−	−	−
77	...do	Giesboro Point, Maryland side.	2	Lactose broth.	25	...do	−	a-c-g	+	+	−	+	+	−	+
78	...do	Fort Foote, Virginia side	2	...do	50	...do	+	a-c	+	+	−	+	−	−	−
79	...do	...do	2	Lactose bile	55	...do	+	a-c-g	+	+	−	+	+	−	−
80	...do	Fort Foote channel	2	Lactose broth.	30	...do	+	a-c-g	+	+	−	+	−	−	−
81	...do	...do	2	Lactose bile	100	...do	+	a-c-g	+	+	−	+	+	+	+
82	...do	Fort Foote, Maryland side	2	Lactose broth.	10	...do	+	a-c-r	+	+	−	+	+	+	+
83	...do	...do	2	Lactose bile	60	...do	+	a-c-g	+	+	−	+	+	−	+
84	...do	Fort Washington, Virginia side.	2	...do	60	...do	+	a-c-r	Trace.	+	−	+	+	−	−
85	...do	Fort Washington channel	2	Lactose broth.	40	...do	+	a-c-g	+	+	−	+	+	−	−
86	...do	...do	2	Lactose bile	100	...do	+	a-c-g	+	+	−	+	+	−	−
87	...do	Fort Washington, Maryland side.	2	Lactose broth.	5	...do	+	a-c-r	+	+	−	−	−	−	−
88	...do	...do	2	Lactose bile	65	...do	+	a-c-g	+	+	−	+	−	−	−
89	...do	Whitestone Point, Virginia side.	2	Lactose broth.	50	...do	+	a-c	+	+	−	+	+	+	+
90	...do	...do	2	Lactose bile	60	...do	+	a-c-g	+	+	−	+	+	−	−
91	...do	Whitestone Point channel	2	...do	70	...do	+	a-c-g	+	+	−	+	+	+	+
92	...do	Whitestone Point, Maryland side.	2	Lactose broth.	95	...do	+	a-c-g	+	+	−	+	+	−	−
93	...do	Indianhead, Virginia side	2	Lactose bile	45	...do	+	a-c-g	+	+	−	+	−	−	−
94	...do	Indianhead, Virginia side channel.	2	...do	65	...do	−	a-c-g	+	+	−	+	+	−	+
95	...do	Indianhead, Maryland side channel.	2	Lactose broth.	60	...do	+	a-c-r-g	+	+	−	+	−	+	−
96	...do	...do	2	Lactose bile	70	...do	+	a-c-g	+	+	−	+	+	+	+
97	...do	Indianhead, Maryland side	2	Lactose broth.	40	...do	+	a-c-g	+	+	−	+	−	+	−
98	...do	...do	2	Lactose bile	80	...do	+	a-c	+	+	−	+	−	+	−
99	...do	Possum Point, Virginia side.	2	Lactose broth.	45	...do	+	a-c-g	+	+	−	+	+	+	+
100	...do	...do	2	Lactose bile	20	...do	+	a-c-r	+	+	[1] +	−	−	−	−
101	...do	Possum Point, Virginia side channel.	2	...do	85	...do	+	a-c	+	+	−	+	−	+	−

102	...do.....	Possum Point, Maryland side.	2	.....do........	85	.....do..............	−	a–c–g....	+	+	−	+	+	−	+
103	...do.....	Sewage Pumping Station....	....	Lactose broth.	20	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
104	...do.....	Milk..........................	....	Lactose bile...	......	.....do..............	+	a–c......	+	+	−	+	−	−	−
105	...do.....	Sewage Pumping Station....	....	.....do........	30	.....do..............	+	a–c......	+	+	−	+	−	+	−
106	...do.....	Possum Point, Virginia side channel.	2	Lactose broth.	5	.....do..............	+	a–c–g....	+	+	[2] +	+	+	−	−
107	...do.....	Giesboro Point, Virginia side.	2	Lactose bile...	60	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
108	...do.....	Seventeenth and D Streets..	2	.....do........	60	Litmus lactose agar...	+	a–c–g....	+	+	−	+	+	−	−
109	...do.....	Railroad bridge.............	2	.....do........	70	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
110	...do.....	Giesboro Point channel......	2	Lactose broth.	20	.....do..............	+	a–c–g....	−	+	−	+	+	−	+
111	...do.....	Giesboro Point, Virginia side.	2	Lactose bile...	60	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
112	...do.....	Giesboro Point channel......	2	.....do........	60	.....do..............	+	a–c......	+	+	−	+	+	−	−
113	...do.....	Fort Foote, Virginia side....	2	Lactose broth.	50	.....do..............	+	a–c......	+	+	−	+	+	−	−
114	...do.....	.....do.......................	2	Lactose bile...	55	.....do..............	+	a–c......	+	+	−	+	+	−	−
115	...do.....	Fort Foote channel..........	2	.....do........	100	.....do..............	+	a–c–g....	−	+	−	+	+	+	+
116	...do.....	Fort Foote, Maryland side...	2	Lactose broth.	10	.....do..............	+	a–c–g....	−	+	−	+	+	+	+
117	...do.....	.....do.......................	2	Lactose bile...	60	.....do..............	−	a–c–g....	+	+	−	+	+	−	+
118	...do.....	Fort Washington, Virginia side.	2	Lactose broth.	55	.....do..............	−	a–c–g....	+	+	−	+	+	−	+
119	...do.....	.....do.......................	2	Lactose bile...	60	.....do..............	+	a–c......	+	+	−	+	+	−	−
120	...do.....	Fort Washington channel....	2	.....do........	100	.....do..............	+	a–c......	+	+	−	+	+	−	−
121	...do.....	Fort Washington, Maryland side.	2	.....do........	65	.....do..............	+	a–c–g....	+	+	−	+	+	−	−
122	...do.....	Whitestone Point, Virginia side.	2	.....do........	60	.....do..............	−	a–c–g....	+	+	−	+	+	−	+
123	...do.....	Whitestone Point channel...	2	.....do........	70	.....do..............	+	a–c–g....	+	+	−	+	+	−	−
124	...do.....	Whitestone Point, Maryland side.	2	.....do........	95	.....do..............	+	a–c–g....	+	+	−	+	+	−	−
125	...do.....	Indianhead, Virginia side....	2	.....do........	45	.....do..............	+	a–c......	+	+	−	+	+	+	+
126	...do.....	Indianhead, Virginia side channel.	2	.....do........	65	.....do..............	−	a–c–g....	+	+	−	+	+	−	+
127	...do.....	Indianhead, Maryland side channel.	2	Lactose broth.	60	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
128	...do.....	.....do.......................	2	Lactose bile...	70	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
129	...do.....	Indianhead, Maryland side..	2	Lactose broth.	40	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
130	...do.....	.....do.......................	2	Lactose bile...	80	.....do..............	+	a–c–g....	+	+	−	+	+	−	−
131	...do.....	Possum Point, Virginia side.	2	Lactose broth.	45	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
132	...do.....	Possum Point, Virginia side channel.	2	Lactose bile...	85	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
133	Dec. 18	.....do.......................	2	Lactose broth.	70	Endo..................	+	a–c–g....	+	+	−	+	+	−	−
134	...do.....	.....do.......................	2	Lactose bile...	70	.....do..............	−	a–c–g....	+	+	−	+	+	−	+
135	...do.....	.....do.......................	15	Lactose broth.	30	.....do..............	−	a–c......	+	+	−	+	+	−	+
136	...do.....	Possum Point, Maryland side, channel.	2	Lactore bile...	80	.....do..............	−	a–c–g....	+	+	−	+	+	−	+
137	...do.....	.....do.......................	2	Lactose broth.	40	.....do..............	−	a–c–g....	+	+	−	+	+	−	+
138	...do.....	.....do.......................	15	.....do........	10	.....do..............	−	a–c......	+	+	−	+	+	−	+
139	...do.....	Possum Point, Maryland side.	2	.....do........	30	.....do..............	+	a–c–g....	+	+	−	+	+	+	+
140	...do.....	Indianhead, Virginia side....	2	.....do........	60	.....do..............	+	a–c......	+	+	−	+	+	−	−
141	...do.....	Maryland Point, Virginia side.	2	.....do........	70	.....do..............	−	a–c–g–r..	+	+	−	+	−	−	+

[1] 4 days.

[2] 2 days.

TABLE 21.—*Results of confirmatory tests upon 210 lactose-splitting gas-forming organisms*—Continued.

No.	Date.	Sample obtained from—	Depth.	Fermentation medium.	Per cent gas.	Medium used for isolation.	Motility.	Action on milk.	Indol.	Reduction of nitrates.	Action on gelatin.	Mannite.	Saccharose.	Dulcite.	Raffinose.
	1913.		*Feet.*												
142	Dec. 18	Possum Point, Virginia side.	2	Lactose bile	70	Endo	+	a-c-g	+	+	—	+	+	+	+
143	...do	.....do	2	Lactose broth.	45	.....do	+	a-c-g	+	+	—	+	+	+	+
144	Dec. 19	Sewage Pumping Station		.....do	20	.....do	+	a-c-g	+	+	—	+	+	+	+
145	...do	.....do		Lactose bile	25	.....do	+	a-c	+	+	—	+	+	+	+
146	Dec. 18	Indianhead channel	15	.....do	60	.....do	+	a-c-g	+	+	—	+	+	+	+
147	...do	Indianhead, Maryland side	2	.....do	60	.....do	—	a-c-g	+	+	—	+	+	—	+
148	...do	Whitestone Point, Virginia side.	2	Lactose broth.	30	.....do	+	a-c-g	+	+	—	+	+	+	+
149	...do	Whitestone Point channel	2	.....do	30	.....do	—	a-c-g	+	+	—	+	+	—	+
150	...do	.....do	15	.....do	50	.....do	+	a-c	+	+	—	—	+	+	+
151	...do	.....do	15	Lactose bile	60	.....do	+	a-c-g	+	+	—	+	+	—	—
152	...do	Fort Washington, Maryland side.	2	.....do	5	.....do	+	a-c-g	+	+	—	+	+	+	+
153	...do	Fort Foote, Virginia side	2	Lactose broth.	40	.....do	+	a-c-g	+	+	—	+	—	+	—
154	...do	.....do	2	Lactose bile	70	.....do	+	a-c-g	+	+	—	+	—	+	—
	1914.														
155	Jan. 3	Seventeenth and D Streets	2	Lactose broth.	15	.....do	+	a-c-g	+	+	—	+	+	—	—
156	...do	Railroad bridge	2	.....do	50	.....do	—	a-c-g	+	+	—	+	+	—	+
157	...do	.....do	2	Lactose bile	60	.....do	+	a-c-g	+	+	—	+	+	—	—
158	...do	Giesboro Point, Virginia side.	2	.....do	95	.....do	+	a-c-g	+	+	—	+	+	+	+
159	...do	Giesboro Point channel	2	Lactose broth.	50	.....do	+	a-c	+	+	—	+	+	+	+
160	...do	.....do	2	Lactose bile	90	.....do	+	a-c-g	+	+	—	+	+	+	+
161	...do	Giesboro Point, Maryland side.	2	Lactose broth.	85	.....do	—	a-c-g	+	+	—	+	+	—	+
162	...do	.....do	2	Lactose bile	75	.....do	+	a-c	+	+	—	+	+	—	—
163	...do	Fort Foote, Virginia side	2	Lactose broth.	25	.....do	—	a-c-g	+	+	—	+	+	—	+
164	...do	.....do	2	Lactose bile	95	.....do	—	a-c-g	+	+	—	+	+	—	+
165	...do	Fort Foote channel	2	Lactose broth.	40	.....do	+	a-c-r	+	+	—	+	—	+	—
166	...do	.....do	2	Lactose bile	75	.....do	+	a-c-g	+	+	—	+	+	+	+
167	...do	Fort Foote, Maryland side	2	Lactose broth.	35	.....do	+	a-c-r	+	+	—	+	+	—	—
168	...do	.....do	2	Lactose bile	55	.....do	+	a-c	+	+	—	+	+	—	—
169	...do	Fort Washington, Virginia side.	2	Lactose broth.	25	.....do	—	a-c	+	+	—	+	+	—	+
170	...do	.....do	2	Lactose bile	65	.....do	—	a-c-g	+	+	—	+	+	—	+
171	...do	Fort Washington channel	2	Lactose broth.	30	.....do	+	a-c-g	+	+	—	+	+	+	+
172	...do	.....do	2	Lactose bile	50	.....do	+	a-c-g	+	+	—	+	+	+	+
173	...do	Fort Washington, Maryland side.	2	.....do	90	.....do	+	a-c-g	+	+	—	+	+	+	+

174	...do.....	Whitestone Point, Virginia side.	2	.....do........	60	.....do..............	+	a-c-g....	+	+	−	+	+	−	−
175	...do.....	Whitestone Point channel...	2	Lactose broth.	45	.....do................	+	a-c-g....	+	+	−	+	+	−	−
176	...do.....	.....do......................	2	Lactose bile...	95	.....do................	+	a-c-g....	+	+	−	+	+	+	+
177	...do.....	Whitestone Point, Maryland side.	2	Lactose broth.	25	.....do................	+	a-c-g....	+	+	−	+	+	+	+
178	...do.....	.....do......................	2	Lactose bile...	55	.....do................	+	a-c......	+	+	−	+	+	−	−
179	Jan. 7	Popes Creek, Virginia side...	2	.....do........	80	.....do................	+	a-c-g....	+	+	−	+	+	+	+
180	...do.....	Popes Creek, Maryland side..	2	Lactose broth.	60	.....do................	−	a-c-g....	+	+	−	+	+	−	+
181	...do.....	Maryland Point, Virginia side channel.	2	.....do........	30	.....do................	+	a-c-g....	+	+	−	+	+	+	+
182	...do.....	Maryland Point, Maryland side channel.	2	Lactose bile...	95	.....do................	+	a-c-g....	+	+	−	+	+	+	+
183	...do.....	Possum Point, Virginia side..	2	.....do........	80	.....do................	+	a-c-g....	+	+	−	+	+	−	−
184	...do.....	Possum Point, Virginia side channel.	15	Lactose broth.	60	.....do................	+	a-c-g....	+	+	−	+	+	+	+
185	...do.....	Possum Point, Maryland side channel.	2	Lactose bile...	50	.....do................	+	a-c-g....	+	+	−	+	+	+	+
186	...do.....	Possum Point, Maryland side.	2	.....do........	50	.....do................	+	a-c-g....	−	+	−	+	+	−	−
187	...do.....	Indianhead, Virginia side....	2	.....do........	15	.....do................	+	a-c-g....	+	+	−	+	+	+	+
188	...do.....	Indianhead, Virginia side channel.	2	.....do........	75	.....do................	+	a-c-g....	+	+	−	+	+	+	+
189	...do.....	Indianhead, Maryland side..	2	Lactose broth.	65	.....do................	+	a-c......	+	+	−	+	+	+	+
190	...do.....	Whitestone Point, Virginia side channel.	2	Lactose bile...	60	.....do................	−	a-c-g....	+	+	−	+	+	−	+
191	...do.....	Whitestone Point, Maryland side channel.	2	Lactose broth.	25	.....do................	+	a-c......	−	+	−	+	+	+	+
192	Jan. 10	Indianhead, Virginia side....	2	.....do........	40	.....do................	+	a-c......	+	+	−	+	−	+	−
193	...do.....	.....do......................	2	Lactose bile...	75	.....do................	+	a-c-g....	+	+	−	+	−	−	+
194	...do.....	Indianhead, Virginia, side channel.	2	Lactose broth.	40	.....do................	+	a-c-g....	+	+	−	+	−	+	−
195	...do.....	.....do......................	2	Lactose bile...	60	.....do................	+	a-c-g....	+	+	−	+	+	−	−
196	...do.....	.....do......................	15	.....do........	5	.....do................	+	a-c-g....	+	+	−	+	+	+	+
197	...do.....	Indianhead, Maryland side channel.	2	Lactose broth.	30	.....do................	+	a-c-g....	+	+	−	+	+	−	−
198	...do.....	.....do......................	15	.....do........	40	.....do................	+	a-c-g....	+	+	−	+	+	+	+
199	...do.....	.....do......................	15	Lactose bile...	55	.....do................	+	a-c......	−	+	−	+	+	−	+
200	...do.....	Indianhead, Maryland side..	2	.....do........	30	.....do................	+	a-c......	+	+	−	+	+	−	−
201	...do.....	Whitestone Point, Virginia side.	2	.....do........	85	.....do................	+	a-c......	+	+	−	+	+	....	....
202	...do.....	Whitestone Point channel...	2	Lactose broth.	50	.....do................	+	a-c......	+	+	−	+	+	−	−
203	...do.....	.....do......................	2	Lactose bile...	65	.....do................	+	a-c......	+	+	−	+	+	−	−
204	...do.....	.....do......................	15	.....do........	75	.....do................	+	a-c-g....	+	+	−	+	+	+	+
205	...do.....	Fort Washington channel...	2	.....do........	65	.....do................	+	a-c......	+	+	−	+	+	−	−
206	...do.....	Fort Foote channel..........	2	.....do........	75	.....do................	−	a-c-g....	+	+	−	+	+	−	+
207	...do.....	.....do......................	15	.....do........	65	.....do................	−	a-c-g....	+	+	−	+	+	−	+
208	...do.....	Seventeenth and D Streets..	2	.....do........	70	.....do................	+	a-c......	−	+	−	+	+	+	−
209	...do.....	Railroad bridge.............	2	.....do........	5	.....do................	−	a-c......	+	+	−	+	+	−	−
210	...do.....	Giesboro Point channel......	2	.....do........	5	.....do................	+	a-c......	−	+	−	+	+	+	+

Of 111 cultures enriched in lactose broth, 93 were transferred to endo agar and 18 to litmus lactose agar; while of 99 cultures enriched in lactose bile, 81 were transferred to endo agar and 18 to litmus lactose agar. The following tabulation shows that little difference can be noticed as to what particular members of the *B. coli* group are favored by either enrichment or a selective medium.

	B. communior.	B. communis.	B. aerogenes.	B. acidi lactici.	Miscellaneous.
Lactose broth to	9	1	8	....	....
Litmus lactose agar .... per cent	50	5.5	44	....	....
Lactose broth to	37	13	33	9	1
Endo agar .... per cent	40	14	35	10	1.1
Lactose bile to	26	0	12	0	0
Litmus lactose agar .... per cent	33	....	67	....	....
Lactose bile to	29	5	37	8	2
Endo agar .... per cent	36	6.2	46	10	2.5

In the case of three organisms which could not be classed with the *B. coli* group, one was enriched in lactose broth, the other two in lactose bile, and all were then transferred to and isolated from endo agar.

Based upon the classification in the "standard methods," the 210 organisms are distributed as follows:

B. communior.	B. communis.	B. aerogenes.	B. acidi lactici.	Miscellaneous.
81	19	90	17	3
39 .... Per cent	9	43	8	1.4

Distributed according to varieties they fall into the following groups:

	A	A_1	A_2	A_3	B	B_1	B_2	C	D	Total.
B. communior	......	72	7	......	......	......	......	2	......	81
B. communis	1	......	......	......	18	......	......	......	......	19
B. aerogenes	......	33	6	......	......	......	51	......	......	90
B. acidi lactici	......	......	4	......	12	......	......	......	1	17

It is interesting to note in this connection that Howe's "metabolic gradient" (E. C. Howe, Science, N. S. XXXV, p. 225) is more or less confirmed by these results. Of the 126 organisms which fermented raffinose only 5, or 4 per cent, also ferment saccharose. Arranging the sugars in the sequence suggested by Howe, the following is the result: Dextrose,[1] 207+; lactose, 207; saccharose, 183; raffinose, 126.

[1] As lactose was used in the routine enrichment medium from which the original cultures were isolated, the number of dextrose + lactose organisms are not indicated by these results.

If all the stations above, and including Whitestone Point cross-sections, be grouped together as instances of comparatively recent pollution and those below that point as representing older pollution. the distributions of organisms is as follows: First group—*B. communior*, 35.3 per cent; *B. communis*, 7.4 per cent; *B. aerogenes*, 48.4 per cent; *B. acidi lactici*, 9 per cent. Second group—*B. communior*, 45.3 per cent; *B. communis*, 12 per cent; *B. aerogenes*, 37.3 per cent; *B. acidi lactici*, 4.8 per cent. The two groups which ferment saccharose—i. e., *B. communior* and *B. aerogenes*—comprised together 83.7 per cent of the whole number in the upper area and 82.6 in the area below Whitestone Point. It would appear, however, that the organisms which ferment dulcite are more resistant, for they occur in larger proportion in the lower area. These results are more or less in accord with the observations of other observers working with somewhat similar waters in temperate regions (Houston, 1911, 7th Report on Research, Metropolitan Water Board, London).

In conclusion, it may be said that of the 210 organisms which produced gas from lactose and which gave a positive reaction on litmus-lactose agar or endo agar 98.58 per cent were members of the *B. coli* group, as defined by the Standard Methods of the American Public Health Association. About the same proportion of organisms which gave positive *B. coli* characteristics on litmus-lactose agar and on endo agar were confirmed by the methods described.

For the examination of large numbers of samples, and where there are probably few organisms present, endo medium has a greater range of usefulness than litmus-lactose agar, because a greater quantity of the suspected culture can be transferred to the former. Where only a few samples are handled at irregular intervals, it is possible that litmus-lactose agar may be more convenient, but by using the modifications suggested, in the preparation and use of endo-agar plates, this medium is made easier to handle and more efficient than litmus-lactose agar in the average laboratory.

The use of an endo plate along with the lactose-broth tube is easy to apply, and so increases the reliability of the bacteriological test that this procedure is recommended as a standard method for conditions similar to those which exist in the Potomac River.

Observations comparing agar and gelatin counts.—Much discussion has taken place as to the relative merits of the agar and gelatin counts in the bacteriologocial examination of water. It is generally admitted that the counts are not the same, nor is there a constant ratio between the counts on agar at 27° and on gelatin at 20°. The question to be settled, therefore, is which gives the more useful information concerning the condition under study? From a bacteriological point of view it seems natural to expect that the organisms growing

at body temperature would give a better indication of the sewage contamination. The ratio between the agar count and the number of *B. coli*, given in Table 14, proves that this is to a limited extent true. On the other hand, there is no doubt that the conditions of the Potomac, as regards rainfall and surface wash and the consequent variation in turbidity, are closely indicated by the gelatin count; for the curves of stream flow, turbidity readings and gelatin count are almost parallel. Theobald Smith in 1886 (Medical News, 1887, vol. 50, p. 404), discussing the bacterial content of the Potomac River, says: "It became possible to anticipate quite accurately the number of bacteria present by looking at the water in the tube by transmitted light." It is, moreover, during the time of high-stream flow with excessive surface wash, and when the time required for the transmission of germs from the source to the victim is short, that the danger of pollution is greatest. The gelatin counts, therefore, although they may not represent actual sewage contamination in the Potomac, do vary with factors which correspond to conditions of danger.

The seasonal variation of the ratios between the agar and gelatin counts for the year are given in Table 22. During the summer months the gelatin count is almost the same as the agar count. Gradually, as the temperature falls and the stream flow rises, the proportion of gelatin to agar count becomes larger. In February the ratio jumps until the gelatin count becomes sixteen times as great as the agar. It should be noticed that it is in the winter months, when the agar gives a much smaller proportional count than the gelatin, that the river water is in its most highly contaminated condition. The heavy rains wash the naked soil, with its accumulated surface filth, directly into the river until it becomes a stream of mud. The rapid current carries the infected matter in a surprisingly short time to its destination. Practically no sedimentation takes place in the stream, while, on the contrary, the accumulated sediments of months are scoured out and carried with the water. These are typical conditions of bad water, and though the agar count rises somewhat, it yet does lag behind. The gelatin, on the contrary, rises almost in a parallel curve with the turbidity. Perhaps the organisms washed into the river under these conditions are not sewage forms, but they do indicate a condition which should not be neglected. The sewage forms are best indicated by the test for *B. coli;* other conditions can be determined by turbidity readings or by the gelatin count, the latter being more sensitive.

TABLE 22.—*Seasonal variations in the ratios of gelatin counts at 20° to agar counts at 37° at various cross sections.*

Cross sections.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
Sewage at Washington	0.74	1.34	1.34	1.65	6.50	1.5	....	2.4	7.62	3.71
Giesboro Point	1.24	1.06	1.46	2.65	....	....	....	9.32	7.82	9.56
Fort Foote	1.31	1.15	1.67	3.42	....	....	....	10.95	11.14	12.17
Fort Washington	2.45	.91	.72	2.36	....	....	....	9.79	9.32	13.62
Mount Vernon	2.38	....	....	....	....	....	....	....	....	....
Marshall Hall	1.23	6.18	2.33	2.37	....	....	....	2.00	....	....
Whitestone Point	....	....	....	....	....	....	....	....	10.43	....
Maryland Point	1.41	1.00	2.00	2.75	6.67	4.73	10.88	5.00	9.17	....
Popes Creek	.56	1.64	2.50	2.61	5.50	5.71	22.00	12.00	5.00	8.82
Lower Cedar Point	....	1.16	3.85	3.47	2.65	6.05	17.71	15.23	7.27	8.82
Below Lower Cedar Point	....	1.24	4.19	5.71	4.96	12.19	13.06	13.31	7.21	9.38
Average	1.41	1.84	2.23	3.00	5.25	6.06	15.91	10.89	8.33	9.34
Average monthly temperature (°C.)	21.6	18.6	13.5	8.5	4.5	2.6	3.5	6.6	14.8	....
Average stream flow per second in thousands of cubic feet	3.8	2.8	10.6	15.3	12.7	26.5	20.4	25.1	25.8	12.9
Total rainfall at Washington for month, in inches	5.42	2.41	3.37	2.20	2.29	4.60	2.95	2.27	3.20	1.72

Gelatin is a very sensitive index of changes in a water. Large filtration plants everywhere have recognized its delicacy in giving information concerning processes of purification. The objection usually urged against its use has been the practical difficulty of incubating at 20° a medium which melts or softens at 21°. It requires an excellent incubator running at 20° to insure a maximum temperature of 21°. If the incubator exceeds 21° for a few minutes, the gelatin is softened sufficiently for motile liquifying organisms to work their way into the medium far enough to liquify it rapidly when incubated longer. One solution of this difficulty would be to lower the temperature of incubation to correspond more closely with that of European practice—i. e., from 15° to 18°—and to incubate longer if necessary. Any change in the method of using gelatin which would make it more practicable would be an improvement in the bacteriological examination of water.

[For a summary of the conditions of pollution of the Potomac River see the last section of this report, where pollution and purifications are considered together (p. 227).]

SELF-PURIFICATION OF THE POTOMAC RIVER.

In the preceding section it was found convenient to describe briefly certain effects of purification observed in the upper river—the purification resulting from the action of manufacturing wastes in the Cumberland region, for example. The bacteriological evidence of the progressive purification of the water of the lower river was also presented and discussed to some extent. In the present section a more intimate study of the processes which tend to reduce and finally eliminate the pollution already introduced will be presented. Since these studies could be much more readily made in the lower river (i. e., from Great Falls to the mouth of the river), and the results there were at present of greater practical importance, they were confined largely to this area.

The factors concerned in the purification of streams as it occurs in nature are many, but are reducible on analysis to two main elements—the dying off of the bacteria of pollution and the oxidation of the organic constituents. All agencies of purification require time for their action, and in flowing streams it is important to appreciate the fact that it is the distance in time between successive points of observation and not the distance in miles which is significant. Moreover, the death rates of bacteria in water and the rapidity of oxidation are influenced by the temperature. In chart A these two factors of time and temperature, as they varied during a year, are graphically shown. The summer months are those in which the greatest time is permitted for the action of purifying agencies, and coincidently the temperature is, of course, higher. The section of the river represented in this chart is that in which purification may best be studied, since the pollution by the time the river water has reached Fort Foote has become well distributed throughout the cross section and by the time it has reached Maryland Point has almost disappeared.

PURIFICATION AS INDICATED BY A CONSIDERATION OF THE B. COLI COUNTS.

Since the colon bacillus has been adopted as the index of dangerous pollution from a sanitary viewpoint, a study of its progressive diminution is of interest. Figures showing this diminution downstream have already been presented in Table 12. In Chart B this diminution between the cross sections at Fort Foote and Maryland Point (the

area of greatest purification) is shown, and if this chart be considered in connection with Chart A, the greater sanitary purification permitted by the long time and high temperature under which purifying influences can act becomes apparent. It was hoped by these studies to be able to establish constants representing the death rate of the colon bacillus, and determine with some accuracy the exact effect of the two factors of time and temperature upon them. Owing, however, to the rather small number of cases in which it was possible to collect all of the desired data, it is not felt that the results have sufficient permanent value to warrant their publication. They appeared to show that the death rate of *B. coli* was relatively delayed in the longer periods of time; in other words, that the bacilli died off more rapidly in fresh pollution, and that the death rate was accelerated by increased temperature.

From a theoretical standpoint it has been explained that considering a single bacterial species like *B. coli* and constancy in the factors of purification, the same percentage decrease (or death rate) would occur in successive equal time periods. Accordingly the death rate, or relation between the numbers of bacteria observed at successive times, could be represented by the constant K in the following formula (E. B. Phelps, 1911):

$$\text{Log.} \frac{N^1}{N^2} = KT.$$

in which N^1=the number at first observation; N^2=the number at second observation; T=time interval between observations; K=the constant factor, representing the death rate.

The rate and extent of purification as indicated by the agar counts at successive stations has already been presented in Tables 12 and 13, and Charts E, F, G, H, and I. In order to present graphically purification as shown by the distribution curves, at successive stations and times, it is necessary to resort to solid models. This has been done in figures 18 to 21, for four seasonal periods. The downward slope of the curved surface as it approaches the observer shows the reduction in the pollution with time and as one progresses downstream. The lateral curve of the surface portrays the distribution of the counts at the various stations for the season named on each figure, that is, how much the individual counts varied from one another. Thus if the surface were perfectly horizontal from right to left it would mean that all of the successive counts were identical. Elevations at the reader's left mean variations from uniformity in the direction of high counts, and depressions at the right indicate low counts. There is a rough parallelism between the lines intersecting the surface at the different

cross sections showing the natural uniformity of distribution of bacteria at the various stations. Furthermore, in so far as the surfaces themselves are similar do they confirm the hypothesis of Phelps that the death rate of bacteria in water is identical in successive time periods, assuming constant conditions. Their departure from parallelism may indicate the entrance of disturbing factors into the problem of purification; for example, the introduction of fresh local pollution, or the unequal death rates of different species of bacteria.

A STUDY OF OXYGEN DETERMINATIONS AND OTHER CHEMICAL DATA.

Since the great bulk of pollution of the lower river consists of the sewage contributed by the city of Washington, studies of the character of this sewage were necessarily preliminary to the consideration of the purification of the lower river.

AMOUNT AND CHARACTER OF SEWAGE DISCHARGED FROM THE CITY OF WASHINGTON.

Practically all the sewage of the city is collected at the pumping station, located in the southeast section of the city, and is pumped thence under the Anacostia River to two discharge outlets, located near mid-channel at about the southern boundary of the city. The sewage system in the thickly settled section of the city is on the combined plan, and storage tanks are provided at the pumping station for the retention of storm water in excess of the normal dry-weather pumping capacity. Storm-water pumps are also provided for handling this excess flow.

Sampling technique.—During eight months, from October, 1913, regular daily samples of the sewage delivered at the pumping station have been collected. These samples were taken between the hours of 8 and 9 a. m. While the character of the sewage varies from hour to hour, so that no single sample is truly representative of the daily discharge, it has been shown, by the experiments of the Massachusetts Institute of Technology upon Boston sewage and in other moderate-sized cities with a single concentration point, that this variation is not great; the early-morning sample is approximately representative of the daily average. A portion of this daily sample has been used in making up a monthly composite, the latter being properly preserved by the addition of chloroform (about 10 c. c. per liter). A second portion of the daily sample has been submitted to routine tests for the determination of its oxygen demand. The composite samples were submitted to the ordinary procedures of

sewage analysis for the determination of suspended solids, oxygen consumed, and the various forms of nitrogen. The methods followed have been, in general, those recommended by the laboratory section of the American Public Health Association and described in the 1912 edition of the Standard Methods of Water Analysis. Organic nitrogen determinations have been made by the method of Whipple, as described in Volume IV, Contributions of the Sanitary Research Laboratory and Sewage Experimental Station, Massachusetts Institute of Technology. The free ammonia was determined by the direct Nesslerization process of the standard methods. For oxygen consumed, the 30-minute period at boiling temperature was employed. The results are given in Table 23.

TABLE 23.—*Chemical data on Washington sewage.*

	Suspended solids.			Nitrogen as—						Oxygen consumed.
				Organic.						
	Total.	Loss on ignition.	Fixed.	Total.	Solution.	Suspension.	Ammonia.	Nitrites.	Nitrates.	
1913.										
August	41.0	20.3	20.7	5.2	4.2	1.0	6.2	0.16	0.34	45.2
September	40.7	31.2	9.5	7.5	6.5	1.0	8.5	.10	.40	31.5
October	41.0	29.5	11.5	5.0	4.6	.4	5.0	.10	....	29.5
December	51.2	32.0	19.2	4.1	3.6	.5	8.4	.19	.44	42.0
1914.										
February	30.2	25.5	4.7	4.9	4.4	.5	5.6	.09	1.02	45.0
March	55.5	34.5	21.0	6.8	5.8	1.0	5.2	.14	1.00	50.0
April	54.0	34.2	19.8	15.2	14.2	1.0	10.8	.15	.45	47.5
May	56.7	36.5	20.2	6.8	5.8	1.0	7.2	.09	.27	42.7
Average	46.3	30.5	15.8	6.9	6.1	.8	7.1	.13	.56	41.7
ANALYSIS OF SAMPLE OF "STORM WATER."										
Jan. 26, 1914	380.0	240.0	140.0	4.5	2.5	2.0	5.5	0.00	0.06	59.2

OXYGEN DEMAND OF WASHINGTON SEWAGE.

As regards the direct effect of this sewage upon the river no useful information is given by the usual analytical determination. For this reason especial emphasis has been laid upon the oxygen relations of the sewage and the stream, the most important single feature of which is the oxygen demand of the sewage itself. Suitable dilutions of the fresh sewage were made in fully aerated tap water, the dilutions varying from 5 to 20 per cent of sewage according to the season. Seasonal changes have been shown to exert a marked influence upon oxygen demand. Whether this is a purely temperature effect or due to seasonal changes in food supply is not known. These dilu-

tions are made in each case in duplicate, and determinations of the free dissolved oxygen are made immediately and at the expiration of a specified time. The loss in dissolved oxygen occurring in the interval gives a measure of the oxygen demand of the sewage. This loss is divided by the corresponding dilution ratio to give the oxygen demand of the undiluted volume of sewage. It has been shown that the process of oxidation proceeds in an orderly manner and at a rate which is approximately a logarithmic function of the time; that is, in equal time intervals an approximately equal proportion of the remaining oxygen demand is satisfied.[1] In the present studies, observations were made in 5 hours and again in 24 hours, in order to check the accuracy of the general formula. From the known 24-hour value and the assumed constancy of the rate of oxidation it is possible to compute the ultimate or total oxygen demand of the sewage in question.

Results.—The results of this work are summarized in Table 24:

TABLE 24.—*Oxygen demand of Washington sewage and estimated loss of dissolved oxygen in the Potomac River, in the absence of reaeration.*

Date.	Sewage flow.	Oxygen demand (parts per million).			Stream flow.	Calculated oxygen loss in stream (parts per million).		
		5 hours.	24 hours.	Ultimate		5 hours.	24 hours.	Ultimate
1913.	*Sec. ft.*				*Sec. ft.*			
September	96.1	24.6	63.7	304	2,775	0.85	2.21	10.5
October	95.1	13.8	48.6	231	10,640	.12	.43	2.06
November	89.3	7.7	25.5	121	15,314	.04	.15	.71
December	89.9	8.1	25.4	120	12,708	.06	.18	.85
1914.								
January	98.3	4.6	21.4	102	26,494	.02	.08	.38
February	99.3	4.3	18.4	88	20,494	.02	.09	.43
March	92.4	4.3	22.7	108	25,104	.02	.08	.40
April	96.4	5.6	20.8	99	25,795	.02	.08	.37
May	96.7	8.9	28.4	135	12,873	.07	.21	1.01

This table also shows the average rate of sewage discharge by months, as well as the average monthly stream flow. From these two figures the dilution of the sewage in the stream can be computed, and upon the basis of this dilution ratio and the oxygen demand of the sewage itself, the actual rate of de-aeration of the stream can be obtained. In the table these calculations of the oxygen loss in the stream are given after 5 hours, based upon the actual 5-hour determination and after 24 hours and ultimately, based upon the 24-hour determinations. The influence of seasonal conditions is strikingly shown. The ultimate demand of the sewage itself varied from 304 parts per million in September to 88 parts per million in February. The combination of high oxygen demand and low-stream

[1] Phelps, E. B., Water Supply Paper 229, U. S. Geol. Surv., 1909, p. 80.

flow in September indicates a rate of de-aeration in the stream itself of 2.21 parts per million during the first 24 hours, as against a rate of 0.09 in February, when the demand was less and the stream flow about 10 times as great. These results illustrate a matter which has been well recognized qualitatively, namely, that maximum nuisance in polluted streams occurs during the summer season.

DISSOLVED OXYGEN STUDIES.

Since this table takes no account of the constant reaeration of the stream, the final column is essentially a statement of estimated oxygen liabilities. In order to determine to what extent these liabilities drain the oxygen resources of the river, it is necessary to estimate the latter by dissolved oxygen studies of the Potomac River water.

During the month of September, that being the month of maximum effect upon the river, dissolved oxygen samples were taken from the following stations: Three Sisters (above the city), railroad bridge, Giesboro Point, Fort Foote, Fort Washington, and Marshall Hall.

Dissolved oxygen in river in September.—At each of these stations a permanent cross section was established by ranges, and nine samples of water were taken each day for examination. These samples were taken from three stations across the stream, one being at midstream and the other two at the one-third and two-thirds point, and at each of these stations samples were collected from depths of one foot, middle depth, and bottom. The results of the examination of these nine samples were averaged to get the value at the cross section. The results are shown in Table 25.

TABLE 25.—*Dissolved oxygen results for month of September, 1913.*

Station.	Parts per million.	Temperature.	Per cent saturation.	Station.	Parts per million.	Temperature.	Per cent saturation.
Three Sisters	8.13	23	93.6	Fort Foote	4.88	24	56.6
Railroad Bridge	6.46	24	74.7	Fort Washington	5.94	23	68.4
Giesboro Point	5.31	23	61.1	Marshall Hall	6.01	23	69.2

It is noticeable that while the dissolved oxygen of the waters above the city is very nearly at the saturation point it decreases rapidly, reaching a minimum at Fort Foote, and then increases to about 69 per cent of the saturation value. The estimated average time of passage between the sewer outlet and Fort Foote during the month of September is five days. The oxygen depletion, computed from the data of Table 24 according to the logarithmic equation previously referred to, would be 7.14 parts per million and would leave a residue

of 0.99 parts per million based upon the up-river value at Three Sisters. It should be noted that the intervening values are somewhat affected by the sewage discharge through tidal action. The difference between the figure 0.99 and the actually observed figure 4.88 gives an approximate measure of the rate of reaeration of the stream. This means that the river water receives about 3.89 parts per million of oxygen in five days under the condition of these observations. This reaeration factor is one of great importance in stream studies, since it determines the capacity of the stream for the oxidation of sewage.

A satisfactory check upon the methods employed in this computation was obtained by determinations of the residual oxygen demand of the polluted water at Fort Foote. Samples of this water were incubated for a 24-hour period and gave, after such incubation, an average value for the month of 4.12 parts per million of dissolved oxygen. The loss on incubation was therefore 0.76. The loss computed from the data of table 24 at the end of five days has been shown to be 7.14. Similar computations for six days give a value of 7.89. The loss between the fifth and sixth day is therefore computed to be 0.75 and actually observed to be 0.76. Similar computations for more distant points have not shown such satisfactory agreement, since the oxidation of the Washington sewage is continuously decreasing and the effect of surface and other pollutions constitutes an ever-increasing percentage error.

These results, however, have been in accord with the known facts, which indicate a constantly decreasing effect of the Washington sewage and an increasing proportional effect of the reaeration factor. A complete study of these phenomena would involve determinations of the oxygen demand of all incoming tributaries and would permit a rather precise computation of the actual magnitude of the reaeration of the Potomac River under existing or any assumed future conditions.

The expression " reaeration " is used in this discussion in its broadest sense and must include all such factors as the influence of microscopic and other plant life. The results reported elsewhere in this report show to what a large extent the green plant life is responsible for the observed aeration phenomena.

Observations in October and November.—Throughout the months of October and November similar observations were made at the Fort Foote station only. The oxygen demand, however, was not determined during these months. The dissolved oxygen for the month of October averaged 6.97 parts per million at a temperature of 16.8°, giving a per cent of saturation of 71.4. Similarly for the month of November it was 10.67 parts per million at 9°, or 91.8 per cent of

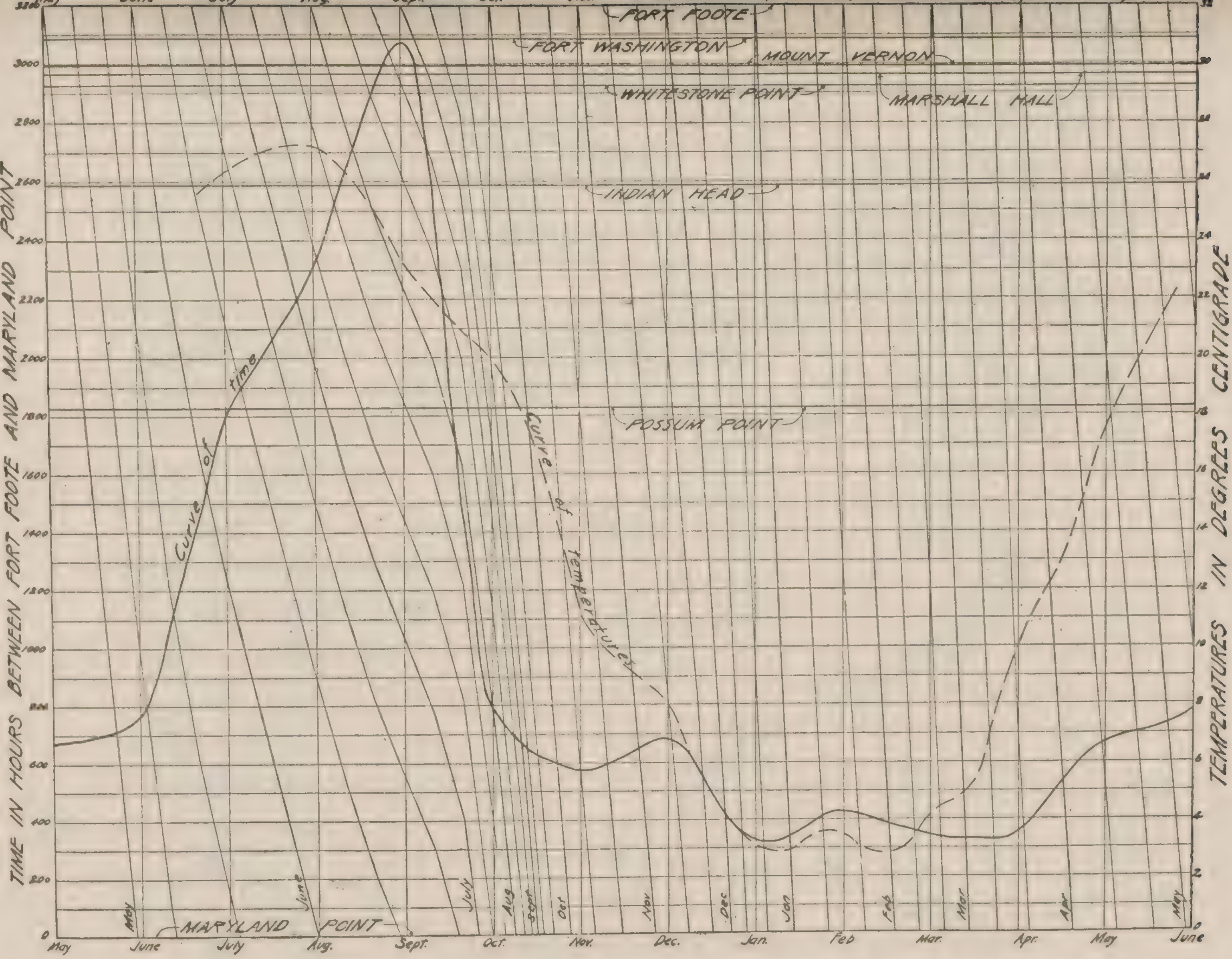


CHART A.—CURVE OF THE STREAM FLOW AND CURVES REPRESENTING THE PROGRESSIVE COURSE OF THE WATER FROM FORT FOOTE TO MARYLAND POINT, THE SECTION OF SELF-PURIFICATION.

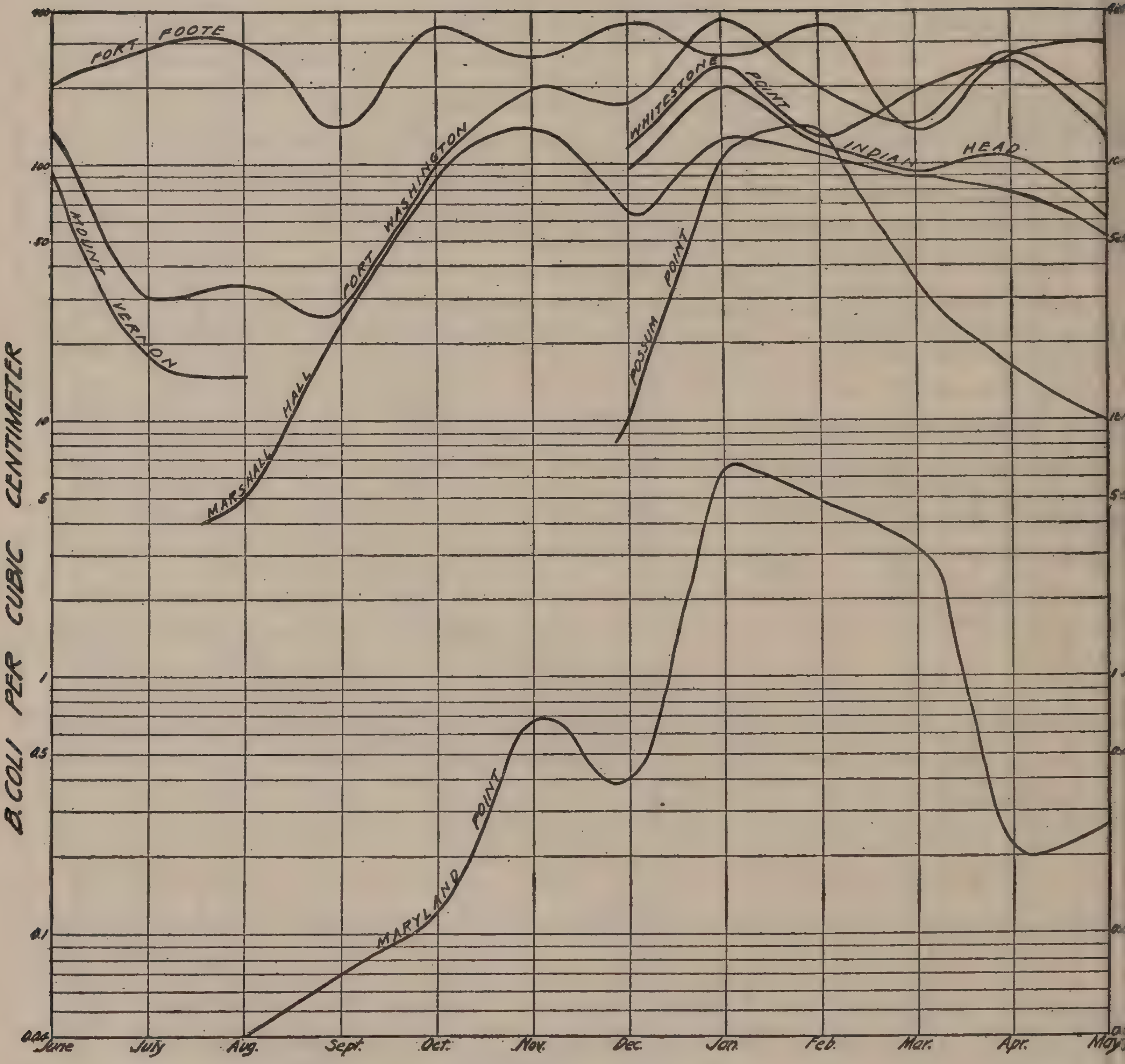


CHART B.—THE AVERAGE NUMBERS OF B. COLI, BY MONTHS, AT EACH CROSS SECTION FROM FORT FOOTE TO MARYLAND POINT.

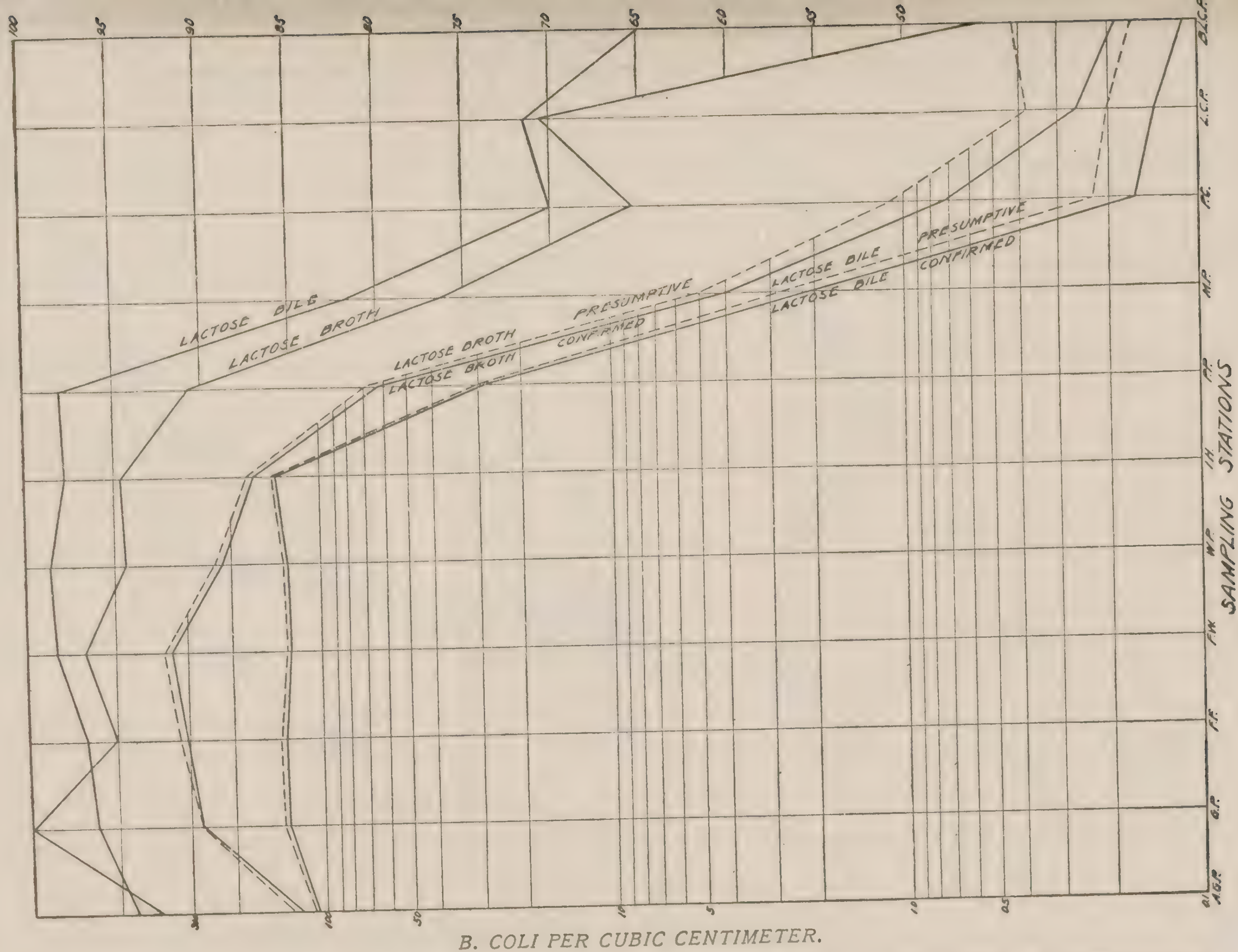


CHART C.—COMPARISON OF THE NUMBER OF B. COLI AT THE VARIOUS STATIONS, AS DETERMINED BY LACTOSE-BILE AND LACTOSE-BROTH, BY THE CONFIRMED AND BY THE "PRESUMPTIVE" METHODS.

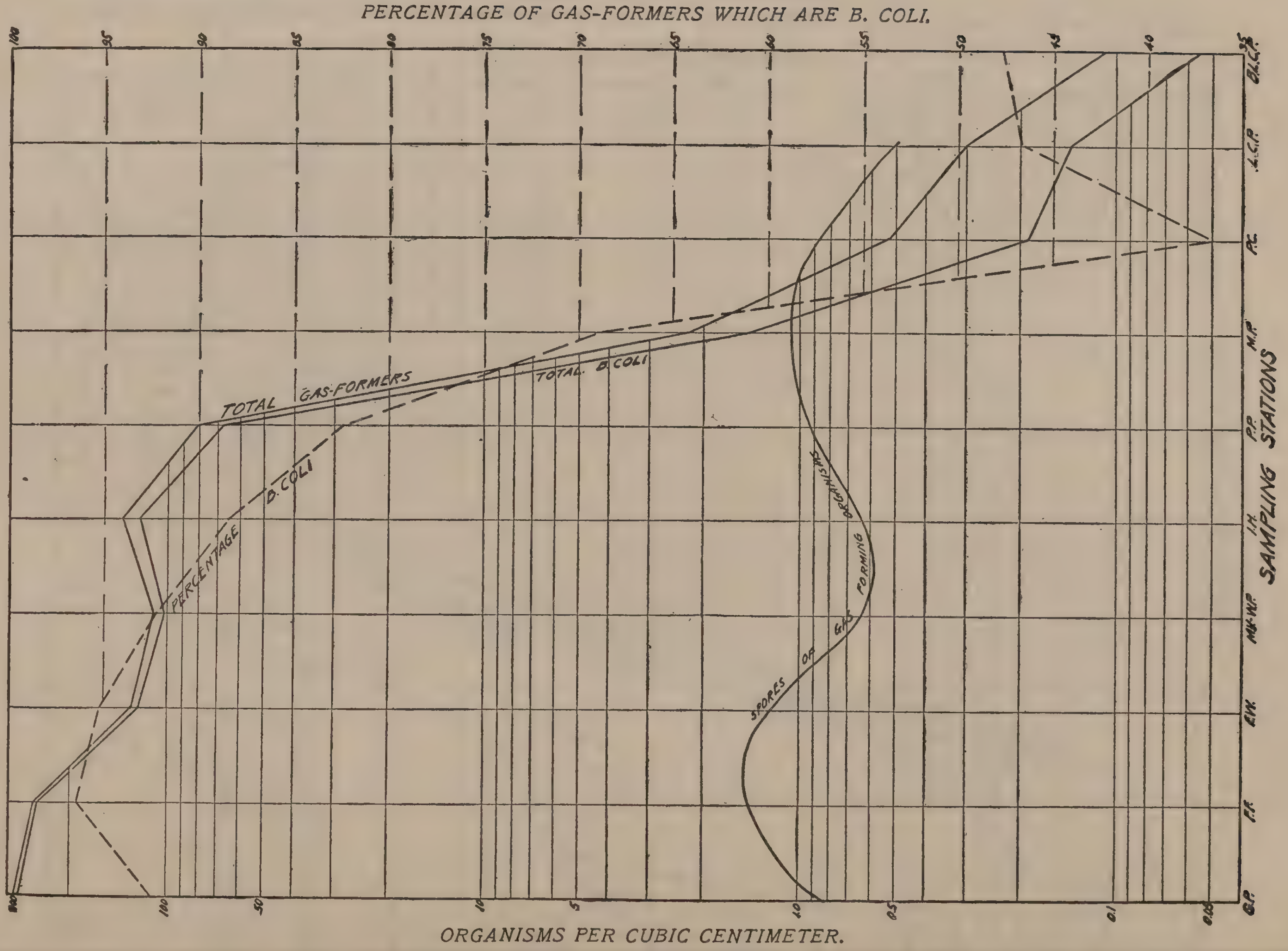


CHART D.—PERCENTAGE OF GAS-FORMING ORGANISMS WHICH

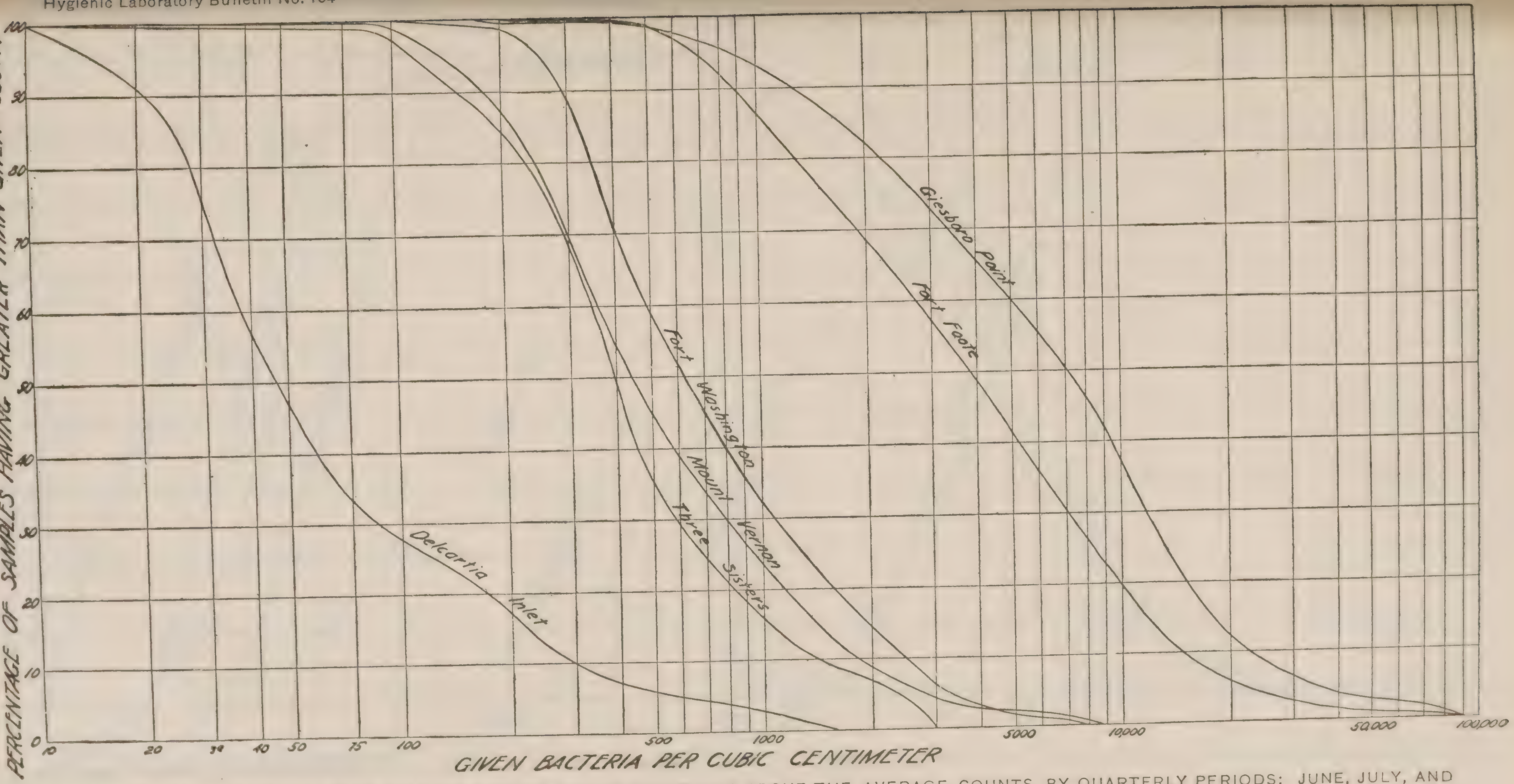
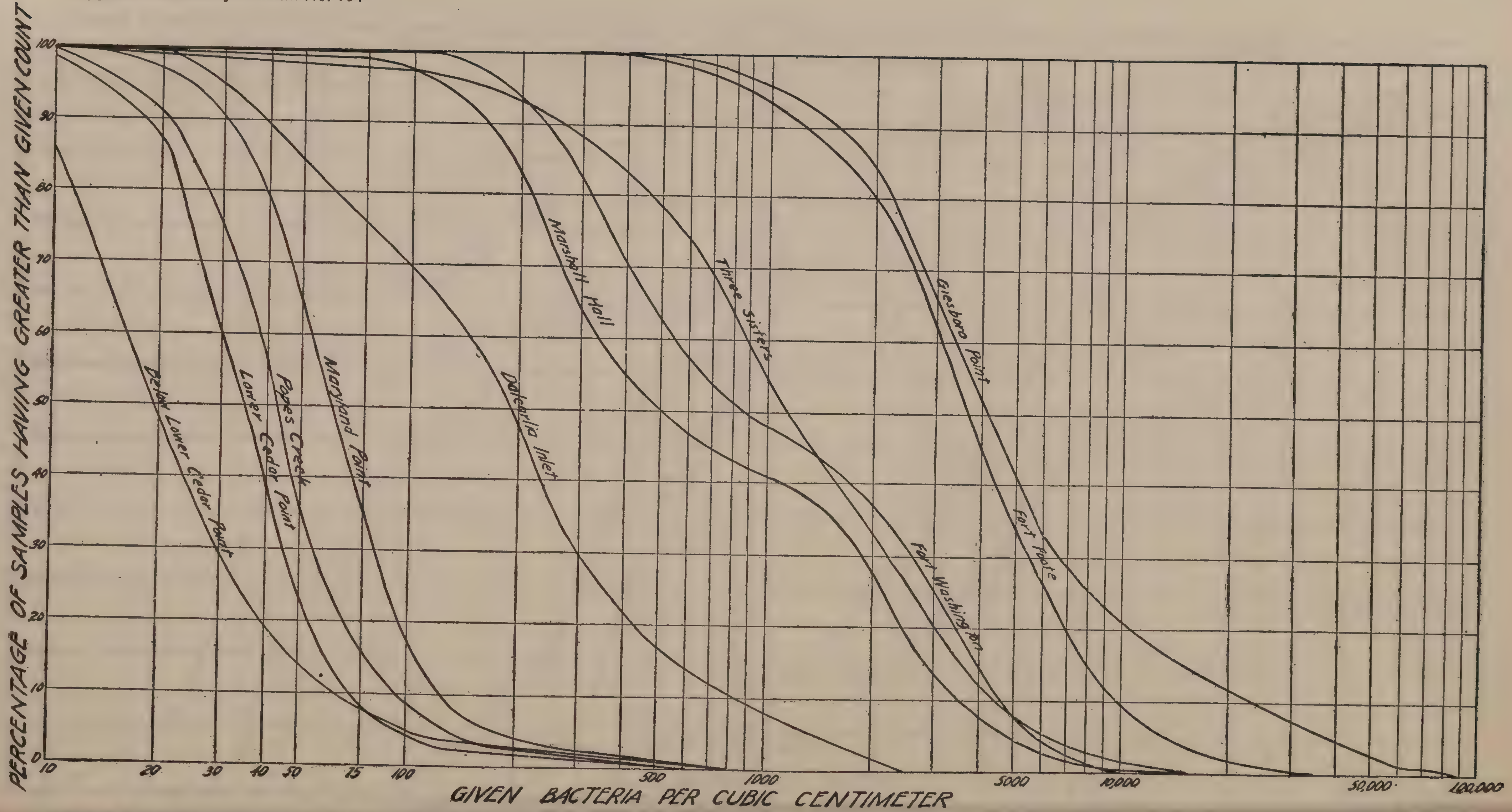


CHART E.—VARIATION FROM THE AVERAGE COUNTS AND PERCENTAGES ABOVE THE AVERAGE COUNTS, BY QUARTERLY PERIODS; JUNE, JULY, AND AUGUST.


PERCENTAGE OF SAMPLES HAVING GREATER THAN GIVEN COUNT
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
75
100
500
1000
5000
10,000
50,000
100,000
GIVEN BACTERIA PER CUBIC CENTIMETER
Marshall Hall
Three Sisters
Giesboro Point
Dalecarlia Inlet
Maryland Point
Popes Creek
Lower Cedar Point
Below Lower Cedar Point
Fort Washington
Fort Foote

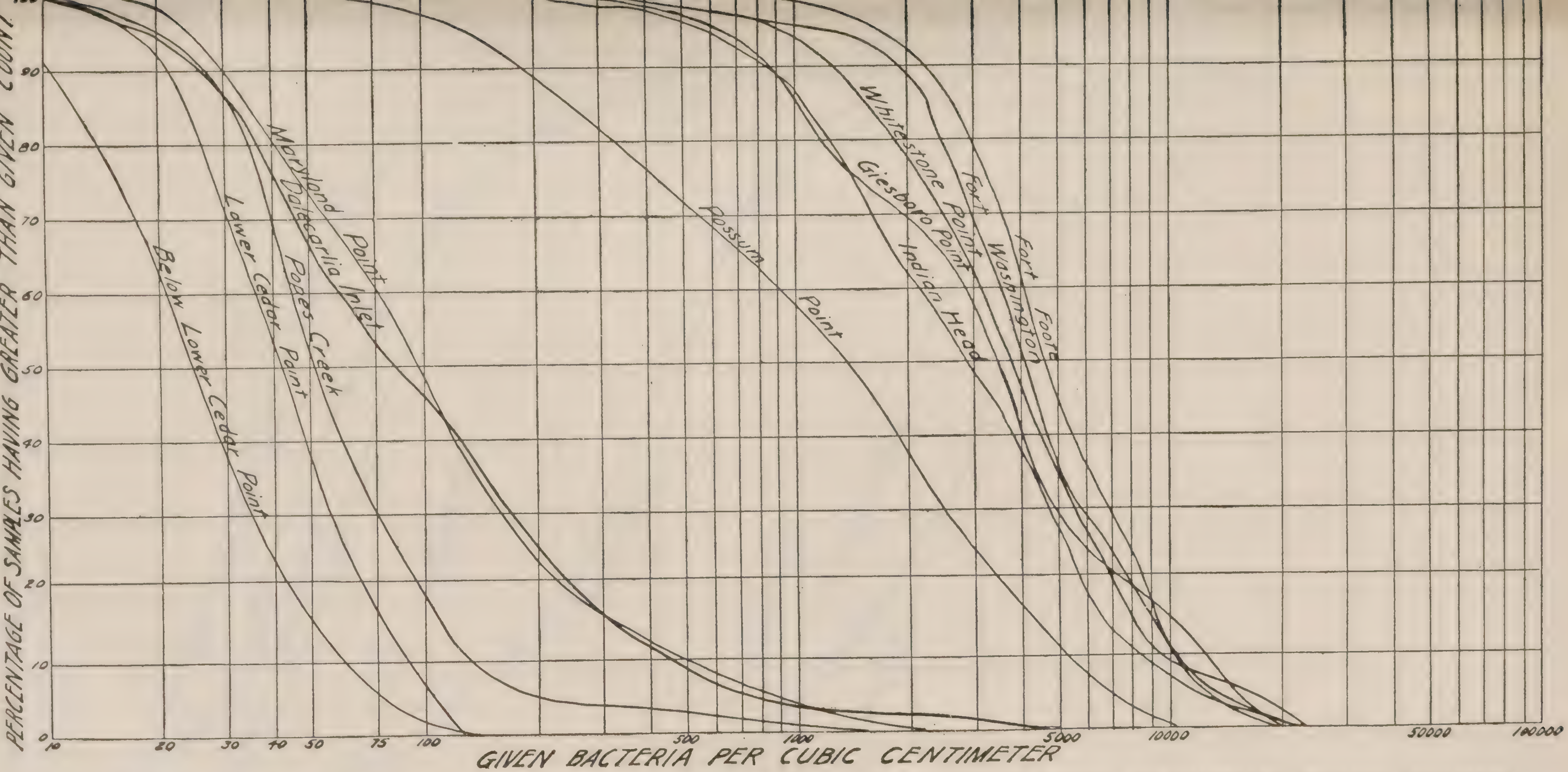


CHART G.—VARIATION FROM THE AVERAGE COUNTS AND PERCENTAGES ABOVE THE AVERAGE COUNTS, BY QUARTERLY PERIODS; DECEMBER, JANUARY, AND FEBRUARY.

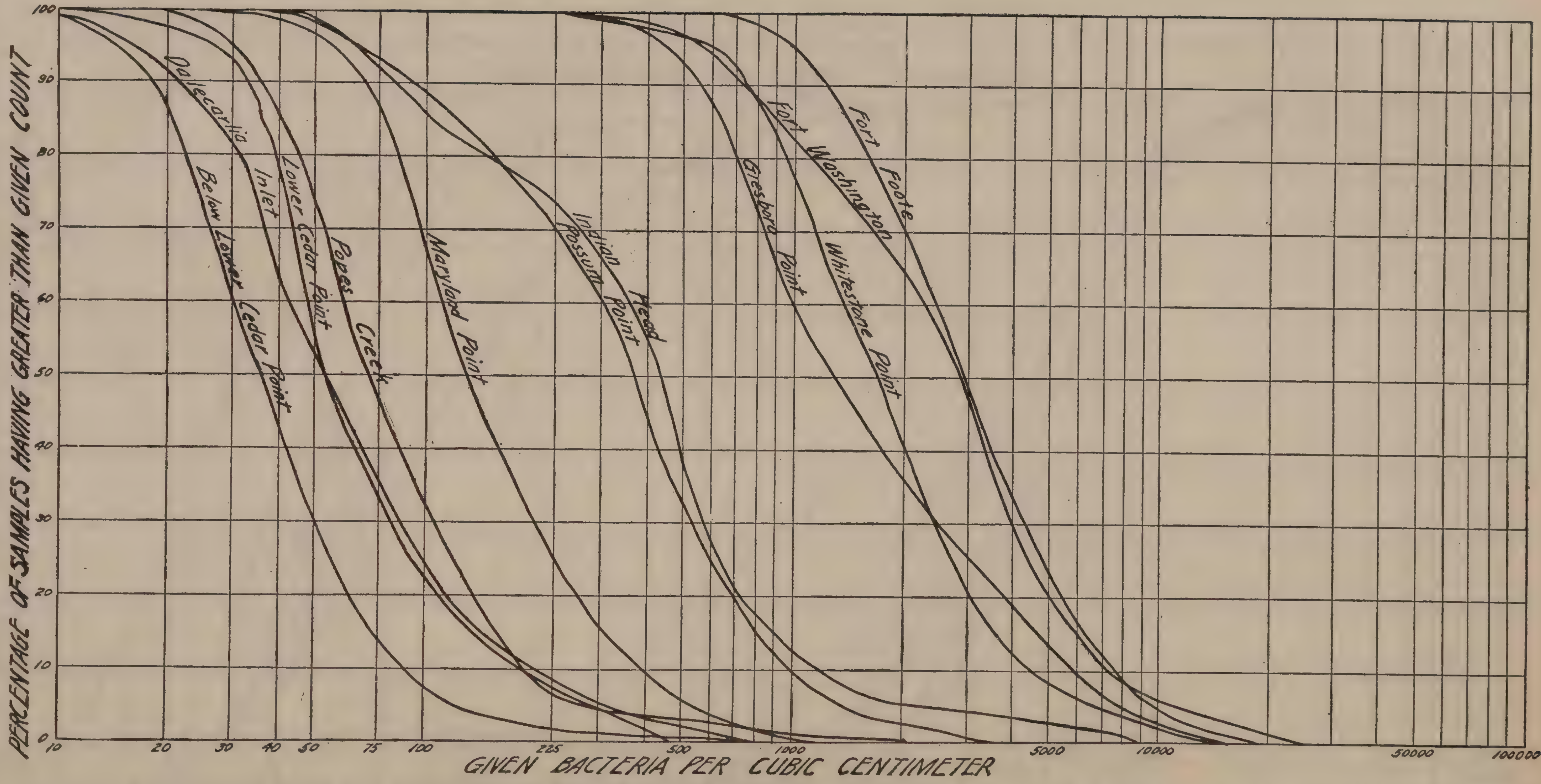


CHART H.—VARIATION FROM THE AVERAGE COUNTS AND PERCENTAGES ABOVE THE AVERAGE COUNTS, BY QUARTERLY PERIODS; MARCH, APRIL, AND MAY.

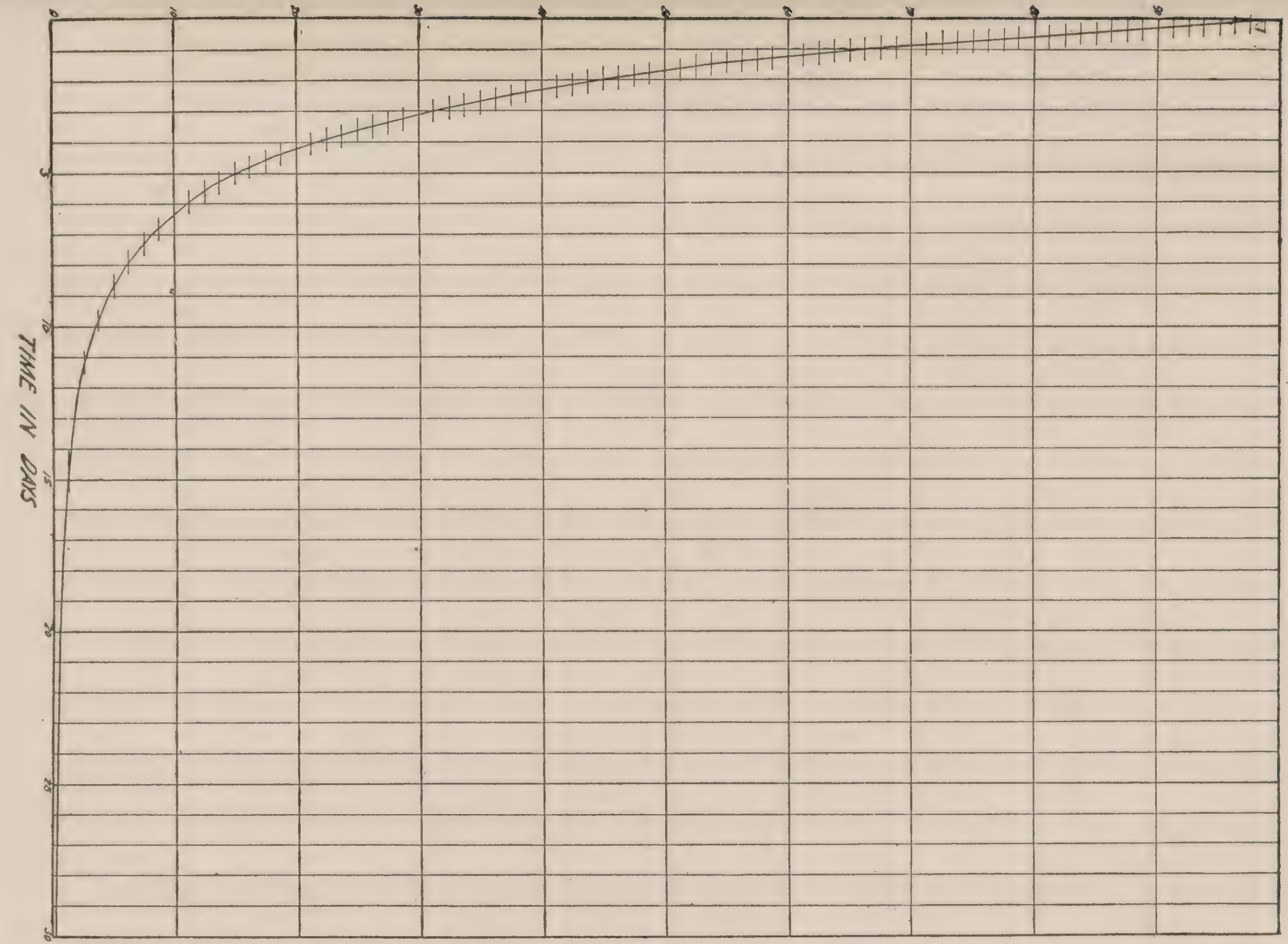


CHART I.—PERCENTAGE OF B. COLI REMAINING AFTER GIVEN TIME BELOW FORT FOOTE.

saturation. The estimated time of passage between the sewer outlet and Fort Foote was 30 hours in October and 21 hours in November. From the data of Table 24 it is calculated that the oxygen depletion in the month of October would have been 0.51 and in November 0.13 parts per million. The actual condition of the river above the city was not determined during these months, so that no actual computations are possible; but it may readily be seen in a general way that a very close correlation exists between the computed oxygen demand of the Washington sewage and the actual observed conditions at the Fort Foote cross section.

Oxygen saturation in critical area.—The most significant figures derived in these studies are those giving the per cent of oxygen saturation in the critical area of the river (Table 25). These show that even at that period of the year when the purifying resources of the river are most taxed they still maintain a balance over the liabilities. This balance is reduced critically at the Fort Foote cross section, but a few miles farther downstream has again become restored well above the point where the danger of nuisance need be considered.

In order that a river may cope successfully with pollution introduced it must have sources from which its oxygen may be constantly replenished. This, of course, is ever present in the air which bathes the surface of the stream, but the rate at which the water can acquire oxygen from this source is limited, and if the pollution be great may require a prohibitive period of time. The Potomac River has, as has been said, an enormous source of oxygen in the vegetation which grows in the natural tidal basins or "flats" which border its lower portion. A further discussion of oxygen in combating pollution will be found in the following article which, on account of its consecutiveness, has been embodied as a separate section of the report, although it deals largely with the subject of the self-purification of the river.

11988°—16——10

POTOMAC PLANKTON AND ENVIRONMENTAL FACTORS.

BY W. C. PURDY.

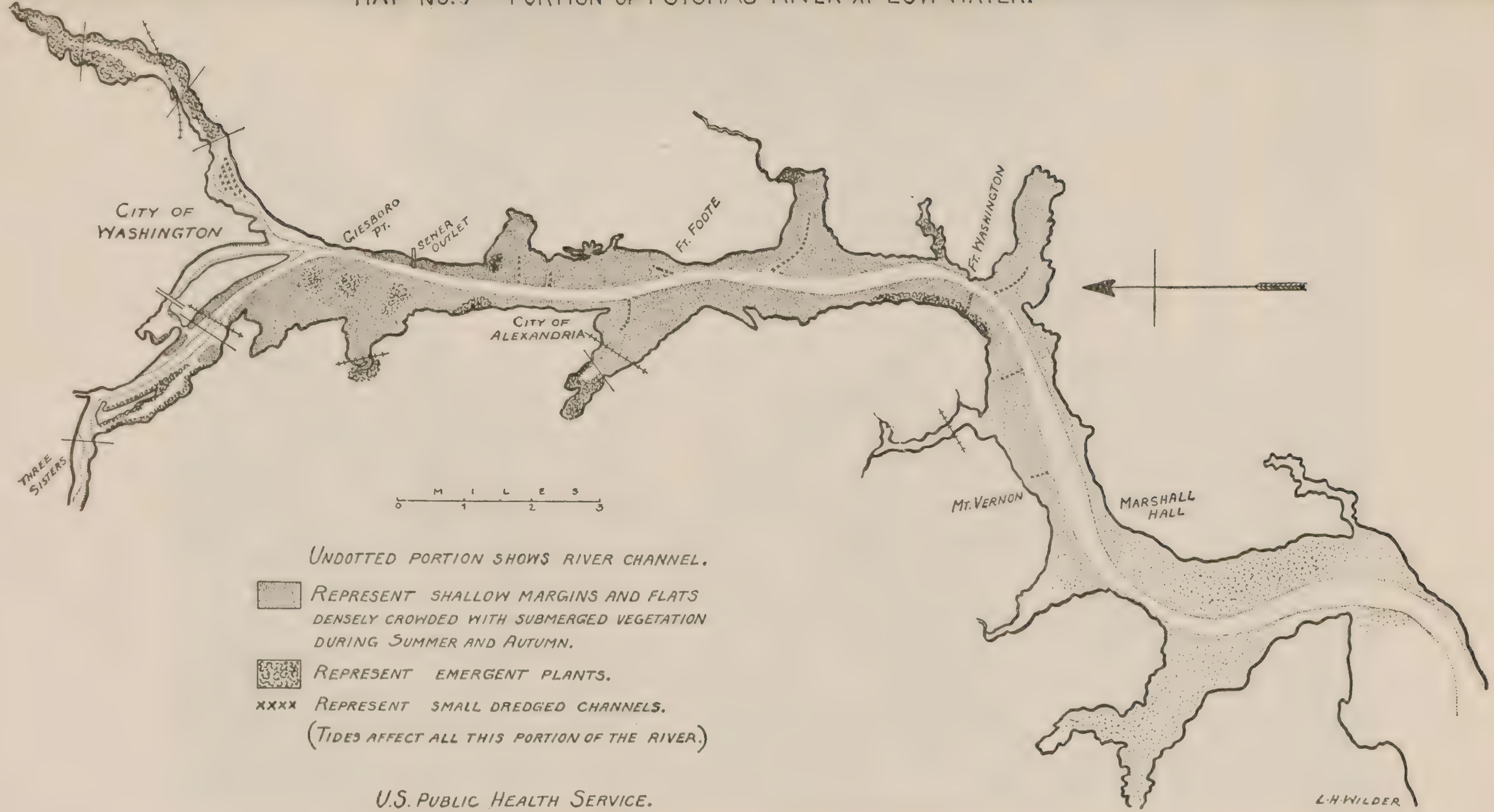
This report is not confined to the activity of the Plankton as such. Manifestly there can be no sharp line of demarcation, as to activity, between the unattached or floating organisms (the Plankton proper), such as *Scenedesmus* or *Protococcus*, and the attached *Coleochaete* or *Oscillatoria* in the immediate vicinity; nor between the free-swimming *Paramoecium* or *Rotifer*, and the *Tubifex*, or *Spongilla* attached, but in the same immediate locality and affecting the same water. A given body of water is subject to many biological influences, not only those incident to the life of freely floating organisms, but also those of the attached forms, such as the larger Algæ, the Potamogetons, Ceratophyllums, Eelgrasses, and various other submerged plants; also the snails, mussels, leeches, turbificid worms, larvæ, etc., which may populate the bottom mud.

Channel and flats.—Biologically and physically, the Potomac below Washington is divided into (1) channel and (2) flats (see map No. 7). The channel is relatively narrow and deep, the water usually more or less turbid and in constant motion, either by reason of current or tides, or both. Conditions are different on the flats. From the latter part of May to November this shallow water contains a marvelous growth of submerged vegetation which checks the movement of turbid, flood-tide water from the channel, causing it to drop its sediment, so the water on the flat is nearly or quite clear, even when a flood of muddy water is passing down the river channel. The dense vegetation also forms sheltered retreats for young fish and for many forms of small aquatic life, and the practically motionless water here affords sufficient time for breeding of these microscopic organisms. In some cases sewage is discharged into the water of these flats, as is the case with Hunting Creek Flat, just below Alexandria.

The tides.—The tides affect the lower river profoundly. The flood tide checks the current, reversing the direction of its flow for a time and spreading the water over the flats, thus causing extensive sedimentation, mingling the turbid water of the channel with the clear water of the flats and thoroughly mixing any sewage in the river with a very large amount of water.

The general effect of the ebb tide is a partial reversal of the conditions just stated. The outgoing tide augments the normal down-

MAP No. 7 - PORTION OF POTOMAC RIVER AT LOW WATER.



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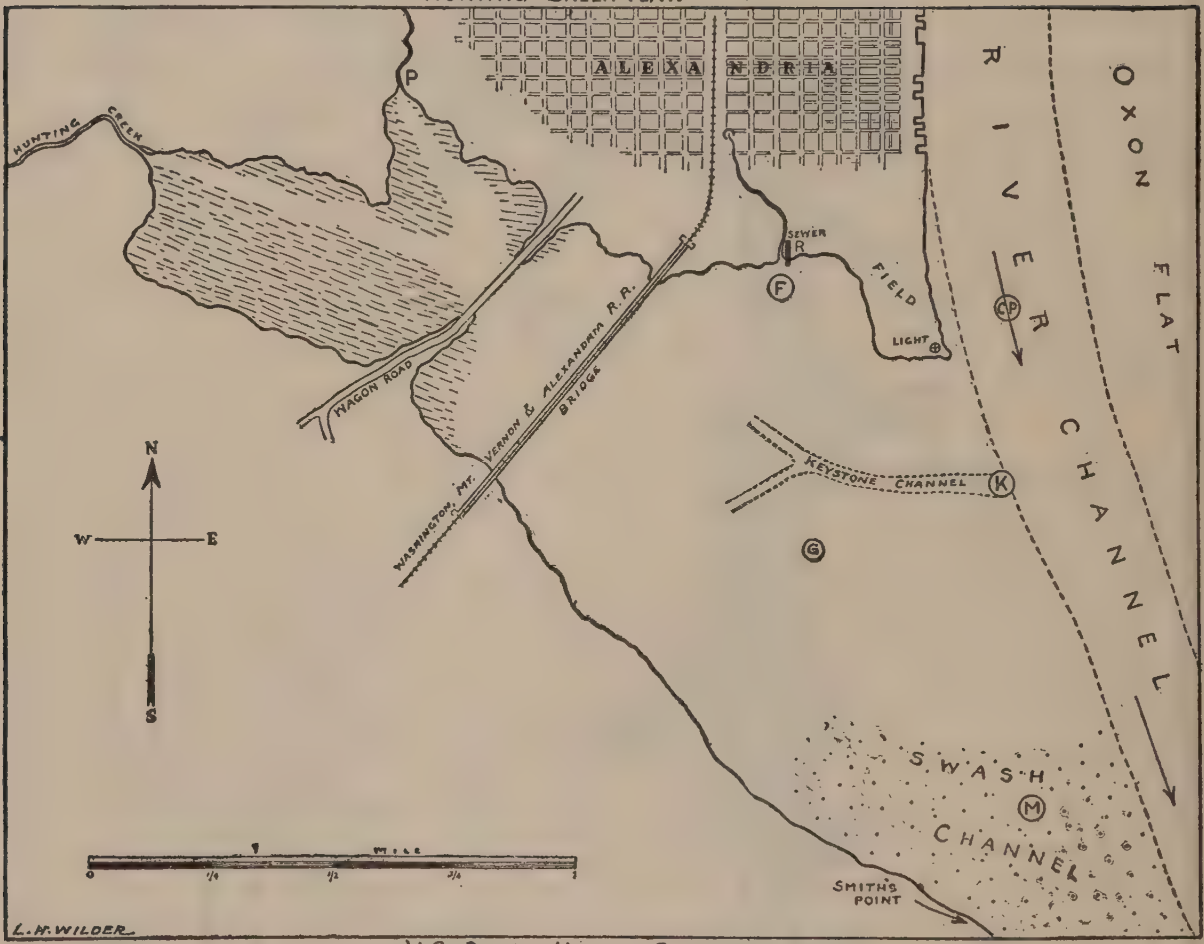
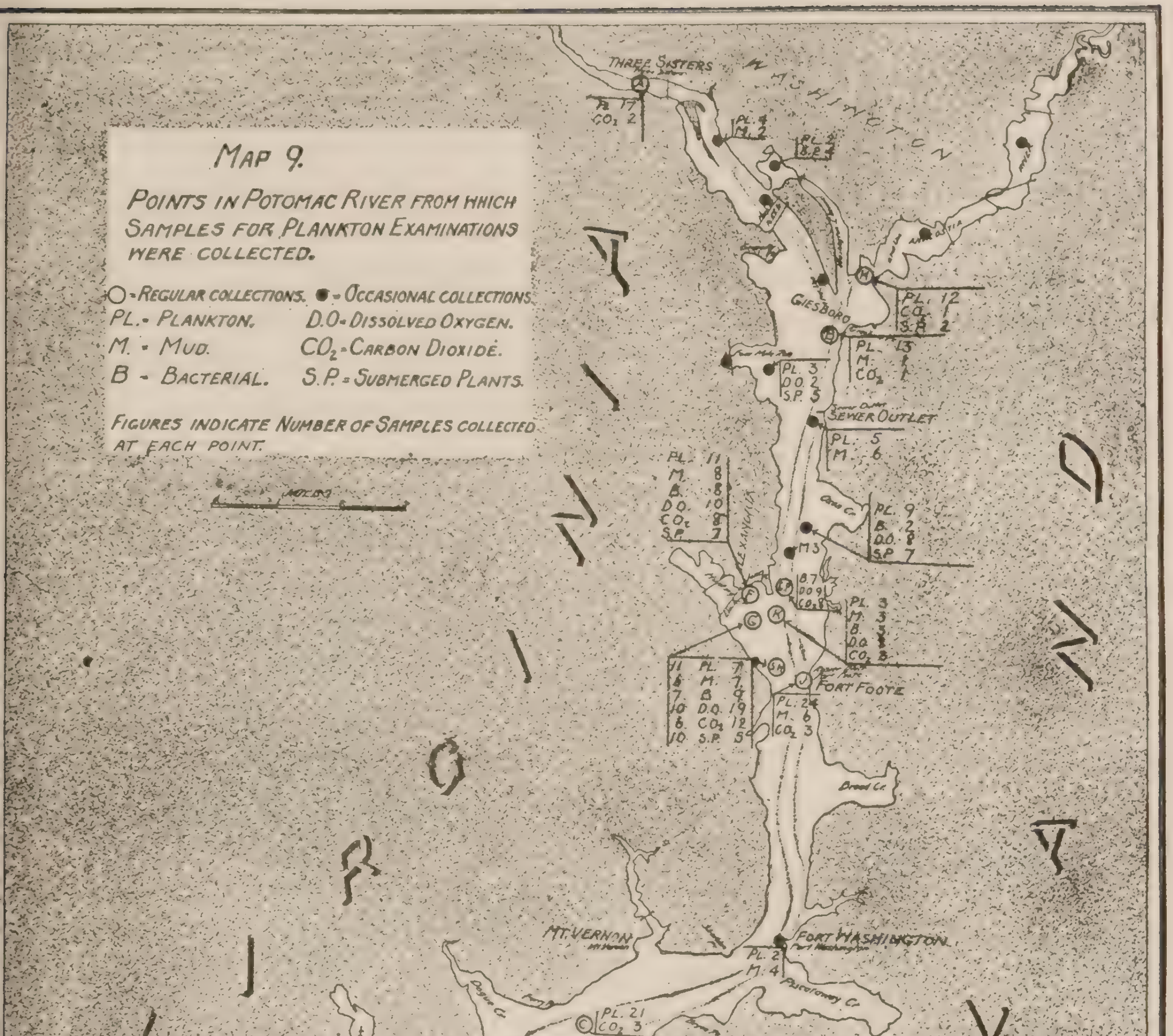
MAP No. 8. — HUNTING CREEK FLAT.



U.S. PUBLIC HEALTH SERVICE.


MAP 9.
POINTS IN POTOMAC RIVER FROM WHICH SAMPLES FOR PLANKTON EXAMINATIONS WERE COLLECTED.
○ - REGULAR COLLECTIONS. ● - OCCASIONAL COLLECTIONS.
PL. - PLANKTON.
D.O - DISSOLVED OXYGEN.
M. - MUD.
CO2 - CARBON DIOXIDE.
B - BACTERIAL.
S.P. - SUBMERGED PLANTS.
FIGURES INDICATE NUMBER OF SAMPLES COLLECTED AT EACH POINT.
THREE SISTERS
WASHINGTON
GIESBORO
SEWER OUTLET
ALEXANDRIA
FORT FOOTE
MT. VERNON
FORT WASHINGTON
WHITESTONE PT.
MARSHALL HALL
GUNSTON COVE
BELMONT BAY
OCCOQUAN BAY
INDIAN HEAD
VIRGINIA
MARYLAND

stream current for a few hours and drains the flats of water which in summer and fall is cleared and oxygenated, and during winter and spring is usually much more turbid than the channel water. At ebb tide these flats become tributaries of no small significance, the sum total of their contribution in a given year being very great.

Thus the river as a whole, represented by the main channel, will be profoundly affected by the character and amount of water from these contributing flats, the effects being physical, chemical, and biological.

The tides produce the effect of greatly increasing the length of the river, inasmuch as the direction of the flow is usually reversed by the flood tide, the water flowing upstream for a time. Thus, the time required for water to flow a given distance downstream is greatly increased. Float experiments during this investigation show that water passes and repasses certain points several times, its net progress downstream between Washington and Mount Vernon, for example, being an average of less than 3 miles per day, but its total movement back and forth with the tides amounting to many miles per day. It will thus be seen that in a given length of the river, as from the sewer mouth to Dogue Run, 13 miles, the total distance traversed by the water back and forth is in all probability several times the actual distance between the two points.

Union of Potomac with Chesapeake Bay.—It seems probable that the river as such does not extend to the point where the Potomac water unites with Chesapeake Bay, but that the actual river mouth is somewhere in that portion between Indianhead and Colonial Beach and that all the lower portion is simply an arm of Chesapeake Bay. Its character as a river has been obliterated by the predominating characteristics of a bay.

Principal pollution.—The untreated sewage of Washington is pumped into the channel at a point about 3 miles below the city. The average daily amount of this sewage is about 60,000,000 gallons. This constitutes the principal pollution to be considered, although a few sewers in Georgetown, emptying into the canal, contribute some sewage, and a few storm-water sewers add street washings and drainage. The city of Alexandria, Va., 5 miles below Washington, also contributes its untreated sewage to the water of the river. It should be noted, however, that much of the Alexandria sewage enters the water of a large flat just below that city, at two points, about three-fourths mile and 1¼ miles, respectively, from the channel of the river proper. (See map No. 9.) This flat has an area of about 1⅓ square miles, with 2 to 5 feet of water at low tide. The sewage that flows upon this flat will necessarily be subjected to certain physical, chemical, and biological actions by reason of the wide expanse of

shallow water, with very slight movement, and densely crowded with submerged plants during summer and autumn. It is possible that this sewage, as such, disappears before reaching the main channel, and therefore adds no polluting material to the river.

The upper Potomac has not been subjected, when it reaches Washington, to any appreciable recent pollution.

Oyster industry.—The lower Potomac is much used for boating. Fishing also is an industry of considerable importance. Oyster fishing in the salt-water portion of the lower river is a large and increasing industry. The great value of these oyster beds naturally brings up the question of possible injury to them by the sewage and wastes in the Potomac River. With a view to obtaining light on this question samples of water were examined to ascertain the number and kinds of microscopic free-floating plants and animals, collectively termed the "Plankton," which are normally present in Potomac water, and to determine as far as possible the mutual effects and reactions between these organisms and the sewage. The complex and intricate conditions of tide, current, turbidity, sunlight, physical conditions, and chemical content which obtain in different parts of the Potomac constitute some of the factors in this problem of which the Plankton content is in part the biological expression. This biological work was carried on simultaneously with the main bacteriological and chemical investigation.

The varying physical and biological conditions in the Potomac produce a number of well-marked "biological situations." With reference to these, our collecting places or "stations" were chosen for the study of the river as a whole.

EQUIPMENT FOR FIELD WORK.

METHODS.

Collections from the river channel were made from the tug *Virginia* or from the steamer *Bratton.* A half-inch hose, 50 feet long, weighted, and screened at one end and connected at the other end to a small centrifugal pump, enabled us to secure a representative "vertical" section of water by slowly raising the hose from the bottom as the pump was worked. This sample was delivered into a clean bucket, mixed, and 4 liters filtered through a Sedgwick-Rafter filter. Collections on the flats were made by using an 18-foot rowboat equipped with sail. In the absence of hose and pump a 4-liter collecting bottle, arranged on a two-piece 10-foot pole, was thrust to the bottom of the water and raised to the surface as it filled with water. This outfit was sometimes used instead of the plankton pump in the river channel. (Fig. No. 16.)

Plankton samples.—Plankton samples were filtered at once. To accomplish this a combined filtering stand and field kit was constructed containing suitable apartments for collecting bottle, reagents, sand, sample bottles, etc. Samples were concentrated by the Sedgwick-Rafter filter to 10 or 15 cc., and the catch killed by addition of enough alcohol to make a 50 per cent solution. At the laboratory the catch was allowed to settle until the next day, when part of the alcohol was removed with a pipette and enough 95 per cent alcohol added to the catch to bring the contents up to about 70 per cent strength. In this the catch was preserved.

Catches from the lower river were preserved by adding a little 40 per cent formalin. It was found that preservation by use of alcohol caused the formation of crystals, probably from some salt in solution in the water, but insoluble in alcohol.

The volume of the catch was measured by centrifuging in graduated tubes, at a medium rate of speed, until the supernatant liquid was clear. This required, usually, $1\frac{1}{2}$ to 2 minutes, depending somewhat on the character of the catch. In all cases careful note was taken of any irregularity in the surface of the centrifuged material, such as the depression in the center, and the volume recorded was duly corrected if necessary.

Counting was done by use of the Sedgwick-Rafter cell and an ocular micrometer ruled in squares. After careful but thorough shaking, 1 cc. of the catch, diluted if necessary, was placed in the cell in the usual manner and 10 fields counted. As each field was examined the relative amounts of plankton organisms, as compared with the silt and amorphous matter in the field, were carefully estimated and expressed in standard units at the bottom of the column representing that field. The two averages, one of plankton and the other of amorphous matter and silt, plus the plankton of the 10 fields, were then taken, and this ratio expressed in per cent used in determining the volume of actual plankton, from data obtained by centrifuging the catch. Thus, if the average of 10 fields is 20 standard units of plankton and 480 standard units of amorphous matter and silt (the layer of material in the counting cell being of uniform thickness), the actual plankton is $\frac{20 \times 100}{(480 + 20)}$ per cent of the volume obtained by centrifuge, or 4 per cent.

Other samples.—Samples to determine the amount of dissolved gases (O and free CO_2) were taken on the flats. A few bacteriological samples were taken at these points also, as the regular daily collections by the tug *Virginia* or the steamer *Bratton* could not cover these stations in the shallow water. Mud samples were collected from both channel and flats during the spring of the year, and various

aquatic plants were collected during their respective seasons of activity.

Mud samples were examined on arrival at the laboratory, the findings being entered under the following headings: Color, odor, consistency, animals present, plants present, organic remains. (See Table 27.)

The total number of each kind of samples taken at various stations is tabulated in Table 26.

TABLE 26.—*Potomac River investigation biological samples (Georgetown to Indian Head).*

Station.	Number of samples.							
	Symbol.	Plankton.	Mud.	Bacteria.	Dissolved oxygen.	Free CO_2.	Submerged plants.	Total.
Three Sisters	A	17	......	......	......	2	......	19
Giesboro Point	B	13	1+	......	......	1	......	15
Mount Vernon or Marshall Hall	C	21	......	......	......	3	......	24
Flat below Alexandria (near sewer)	F	11	8	8	10	8	7	52
Flat below Alexandria (mid flat)	G	11	6	7	10	6	10	50
Mouth of Anacostia River	H	12	......	......	......	1	2	15
Fort Foote	J	24	6	......	......	3	......	33
Keystone Channel below Alexandria	K	3	3	3	8	3	3	23
Smiths Point (flat below Alexandria)	SM	7	7	9	19	12	5	59
Channel near lighthouse below Alexandria	CP	......	......	7	9	8	......	24
OCCASIONAL SAMPLES.								
Flat of Four Mile Run	D	3	......	......	2	......	5	10
Flat of Oxon Run	E	9	......	2	8	......	7	26
Foot of Seventeenth Street	L	4	2	......	......	......	......	6
Near sewer discharge (river channel)	SS	5	6	......	......	......	......	11
Sewer near canal, Georgetown	......	......	7	......	......	......	......	7
Tidal Basin	......	2	......	......	......	......	4	6
River channel, opposite Alexandria	......	......	3	......	......	......	......	3
Fort Washington	......	2	4	......	......	......	......	6
Whitestone Point	......	2	4	......	......	......	......	6
Indianhead	......	3	2	......	......	......	......	5
		149	59	36	66	47	43	400

Mud samples were secured from the river channel by means of a simple conical scoop with bail or handle long enough and heavy enough to insure its proper position for scraping the mud surface on reaching the bottom. This scoop was then dragged a few feet, engaging the mud similar to the action of a "mushroom" anchor. A representative sample of about 200 cc. of this mud was transferred to the laboratory and examined. Other than this no effort was made to examine the mud quantitatively. Mud samples were secured from flats by use of a simple scoop on the end of a pole (fig. No. 16).

From August to December, 1913, and during April and May, 1914, weekly samples were taken at regular stations, although considerable irregularity was caused by extreme turbidity, which made it impossible to get water through the Sedgwick-Rafter filter in sufficient amount to furnish a reliable sample.

Condition of river in winter and early spring.—During winter and early spring the flats were inaccessible on account of ice, and the channel waters were too turbid for the collection of samples during portions of the same season. After the ice disappeared the shallow water on the flats, having as yet no plant growth to protect it, was kept stirred up and turbid by wind, but the channel water was relatively clear, except when the ebb tide drained a flood of muddy water into it from some wind-disturbed flat.

Owing to these conditions the samples as taken were somewhat irregular as to sequence, considering the ten months' investigation as a whole. However, the majority of samples were taken, so far as possible, at the season of greatest plankton activity, and all samples were taken, filtered, preserved, and examined with due precautions to eliminate any source of error in order that each sample might be a true index of the plankton content of the water concerned.

Species of organisms.—The limited time assigned for this investigation, combined with the great difficulty of identification to a certainty of preserved organisms, seemed sufficient justification of our course in not stating as a rule the species or variety. It seemed more important, from a practical point of view, to ascertain why certain organisms were present and others absent, why they were few or abundant, and to interpret these findings in terms relative to the condition of the water. In other words, an effort was made to use the plankton content, and the bottom forms as well, as a pollution index, following in this respect the general plan of the excellent report on the Biology of the Upper Illinois River,[1] by Dr. S. A. Forbes and Prof. R. E. Richardson. These gentlemen distinguish three stages of impurity by applying to water and its characteristic biological content the terms: (1) Septic or saprobic, (2) polluted or pollutional, (3) contaminated or contaminate, and, (4) finally, "clean water," the terms as given being in the order of diminishing impurity. We have attempted in the following table to associate these terms with the physical, chemical, bacteriological, and biological conditions of water that corresponds thereto:

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[1] Bull. Ill. State Lab. of Natural History, Vol. IX, Art. X, June, 1913.

Characteristics.

Water.	Physical.	Chemical.	Bacteriological.	Biological.
Septic or saprobic.	Water discolored with suspended matter, sewage, and microscopic organisms. Offensive odor. Bubbles of gas arising from bottom. Sticky, dark-colored mud, with offensive odor.	Dissolved oxygen low, ranging from 0 to 20 per cent of saturation. High CO_2 (free) as a result of decomposition. Very high ammonias and nitrites. Nitrates low or absent.	Very high 20° count. *B. coli* in one ten-thousandth c. c. or less.	Persistent presence of Infusoria in large numbers. (*Paramoecium*, *Colpidium*, *Carchesium*, *Epistylis*, etc.) Microscopic worm *Dero* often present. Fungi such as *Saproleguia*, *Leptomitus*, *Beggiatoa*, and *Sphaerotilus* are usually the only plants present. Mud contains many "slime worms," such as *Tubifex* and *Limnodrilus*.
Polluted.	Discoloration and offensive odor only occasional. Bubbles only in warmer weather. Bottom mud dark, somewhat sticky, with some offensive odor.	Dissolved oxygen may range from 15 to 60 per cent of saturation. Free CO_2 is high, about 5 to 10 parts per million. Ammonias and nitrites high.	Bacterial count high. *B. coli* present in one-tenth to one-thousandth c. c. as a rule.	Smaller protoza such as *Difflugia*, *Anthophysa*, *Vorticella*, etc., are present, also certain rotifers and small crustaceans. Prevailing plants are the blue-green algæ, also *Beggiatoa* and certain diatoms. Mud contains slime worms, and sometimes snails and young mussels.
Contaminated.	No discoloration, odor, nor bubbles from bottom. Accumulated bottom mud granular rather than sticky, and with no offensive odor.	Dissolved oxygen is uniformly high, about 70 to 100 per cent of saturation. Moderate amount of ammonias and nitrites with high nitrates. Free CO_2 varies from 2 to 6 parts per million.	Count at 20° moderate, ranging from 100 to 5,000 per c. c. *B. coli* in 1 c. c. and sometimes in one-tenth c. c.	Characteristic animals are green flagellates, such as *Englena viridis*, *Phacus*, etc , with crustaceans (*Cyclops*, *Grammarus*, etc.) in moderate numbers. Sponges and Bryozoa may be attached to sticks, plants, or pebbles. Unicellular and filamentous green algæ are usually present. Blue-greens are occasional. Diatoms are numerous. Bottom mud contains mussels, snails, and larvæ of insects.
Clean.	No discoloration, odor, nor bubbles. Accumulated mud on bottom is without special odor, may be light or yellowish in color, and is not sticky.	Dissolved oxygen is usually at the saturation point. Ammonias and nitrites are very low or absent. Nitrates may be high or low. Free CO_2 about 1 to 2 parts per million.	Total count at 20° may range from 100 to 1,000 per c. c. *B. coli* usually present in 10 c. c., but not in 1 c. c.	Microscopic animals are few, consisting chiefly of a few rotifers and constaceans. There is a noticeable absence of septic and pollutional organisms. Many diatoms may be present, especially *Navicula*. Green algæ in moderate amounts are along edges of stream. Clean bottom is populated with larvæ of stone fly, May fly, etc., also mussels and crayfish may be present.

THREE SISTERS.

This station, a short distance above Aqueduct Bridge and opposite Georgetown, was chosen because the water has not yet been contaminated by sewage from either Georgetown or Washington, although a small amount of pollution is introduced by the intermittent overflow of the Chesapeake & Ohio Canal, into which a few small sewers and at least one large one discharge.

This is the lower end of the narrow, turbid, swift upper Potomac, the "young" portion of the river. Moreover, the water here has not yet had access to the flats which characterize the lower river below

Washington. The raw, turbid water is as yet untreated by these vast aeration and sedimentation basins.

Plankton samples (see Figs. 22 to 53).—During August, 1913, these showed 4,500 diatoms per liter of water. Blue-green algæ amounted to 2,100 standard units per liter. (There are 2,500 "standard units" in 1 square millimeter, or 1,562,500 in 1 square inch.) The green algæ slightly exceeded the blue-green in amount. Rhizopods were present in small numbers, about 250 per liter. Infusoria averaged 250 per liter and rotifera 112.

The organisms in this list that would arouse suspicion as to the purity of the water are the blue-green algæ, the rhizopods, and the infusoria. The latter, however, were composed almost wholly of *Codonella*, which Prof. Kofoid[1] regards as indifferent to sewage or not dependent on the presence of sewage organisms for food.

The river is comparatively narrow at this point, and the limited overflow from the contaminated canal and other local pollution would seem to be sufficient explanation for the presence of small amounts of blue-green algæ and small numbers of rhizopods, especially as some of the samples were collected during flood tide, when the marginal waters would be more perfectly mixed with the channel waters.

September samples contain per liter of water organisms as follows: Diatomaceæ, 5,200; blue-green algæ (unicellular), 2,200; fungi (*Crenothrix*), 1,300 standard units; rhizopods, 200; mastigophora, 420, chiefly *Euglena viridis* and *Trachelomonas;* infusoria, 330, principally *Codonella* and *Halteria.* A few crustacea (*Cyclops*) were found, the majority being in the nauplius stage. *Anguillula*, a microscopic worm, was present in small numbers in one sample.

The presence of organisms in number and kind essentially the same as were found during September would seem to indicate that the water was still occasionally affected by small quantities of pollutional material, not sufficient, however, to give rise to a rapid increase of those organisms that find their food in organic matter. The persistent presence of large numbers of *Euglena viridis*, for example, would be just ground for suspicion, because they multiply rapidly in water rich in organic matter. The small number of these organisms in the water would tend, therefore, to demonstrate that the water is reasonably pure.

October showed about the usual number of diatoms (4,800) until October 21, when a considerable increase was noted. This increase was made up chiefly of *Nitzschia*, of which there were 46,000 per liter, running the total diatom count up to 55,000. Very few organ-

[1] Bull. Illinois State Lab. Nat. Hist., Vol. VIII, Art. I, p. 122.

isms other than diatoms appeared in this sample, with the exception of a unicellular green alga, *Protococcus*, which numbered about 2,000. Another catch taken October 16 showed a few *Arcella*, a rhizopod which normally inhabits the bottom ooze, but occasionally is buoyed up gases or disturbed by water currents, hence its occasional presence in the plankton or floating organisms. None of the organisms mentioned would arouse suspicion as to the condition of the water. The plankton population seems to be that of a water of average degree of purity or better.

Three collections were made in November—the 4th, 18th, and 25th, respectively. The turbidity of the three samples was 55, 150, and 45, respectively, with temperatures of 11°, 8°, and 10°. It is probable that the disturbed hydrographic conditions resulting in the high turbidity of November 18 were largely responsible for the considerable fluctuation shown in the diatom content, that of November 4 being 3,000 per liter, the count increasing to 72,000 (chiefly *Navicula* and *Synedra*) in the sample taken November 18, and falling again to 9,000 (largely *Pleurosigma*) November 25.

Blue-green algæ, chiefly isolated strands of *Oscillatoria*, were present in two of the collections. This plant normally grows in mats on the bottom or in shallow water along the edge. Currents caused by floods, or otherwise, or gases generated in the bottom mud will from time to time break up these mats and distribute the small masses of filaments through the upper water, hence the advent of a few of the detached threads in the plankton of the main channel. Normally this plant flourishes in sewage-polluted water. The source of the specimens found in these samples was probably in the polluted water from the canal, or from some small local sewer whose further effect would be unnoticed in the large amount of dilution water.

Difflugia, usually living in bottom ooze or in slimy material on plants, was present in the November 18 sample, about 4,000 per liter. Its presence is of doubtful significance, so far are present knowledge extends, except that its appearance on this occasion was coincident with the disturbed conditions in the river due to rains, and, further, an important factor in its food supply, viz, diatoms, were especially abundant at this time. There had been much rain during November 14, 15, and 16, resulting in a turbidity of 150 when the sample was taken. It is noticeable that this organism did not appear in the collections of November 4 and November 25. In both of these cases turbidity was low, 55 and 45, respectively, there having been no rain for more than a week preceding each collection.

In two samples *Codonella* was found, November 4, 1,000 per liter, and November 25, 5,000 per liter. The food of this organism is sup-

posed to consist chiefly of minute algæ.[1] A minute worm, a nematode as yet unidentified by the writer, was present in this sample.

The evidence derived from these November samples is on the whole favorable, with the possible exception of the organism just mentioned. However, as this nematode was found only in the sample which had been subjected to the disturbed hydrographic conditions and high turbidity, its presence may have been due to the disturbance of decaying plants on which or in which the animal lives or feeds.

Ice and high water prevented collections at this station during winter and early spring. Samples were obtained in March and April, 1914, the last being taken April 13.

The plankton in March consisted mainly of 50,000 diatoms per liter, of which 28,000 were *Synedra*. A few filaments of blue-green algæ were present. No other organisms appeared in significant numbers.

The water in April again showed a majority of *Synedra* (12,000) in the diatom count of 20,500 per liter. *Cladophora*, a green alga normally growing attached to stones, etc., in riffles and in shallow moving water, was present in small amount, probably torn loose from its moorings. The infusorian *Codnella* numbered about 500 to the liter.

It will be seen that the plankton content of the water in March and April showed nothing that would indicate more than a small amount of pollution. It should be noted, however, that the occurrence of the diatom *Synedra* in great numbers is regarded by some workers as an indication of contaminated water.

A certain combination of flood-tide and wind conditions will, in some instances, bring to this sampling point some of the highly polluted water from the wharves, and from the outlet of the canal, located a few hundred yards downstream.

Fish are fairly plentiful in this part of the river. The water has no abnormal odor or color at this sampling station. Rowboats and canoes are much used for pleasure trips, especially upstream. Altogether, the water is that of a normal river, with a relatively small amount of contaminating material which produces no nuisance.

GIESBORO POINT.

The water here has received some polluting material and has had access to Fourmile Flat, comprising about 1,400 acres, this area being covered in summer with a dense growth of submerged plants.

The Anacostia River, or Eastern Branch of the Potomac, joins the river proper just above this sampling point. At ebb tide into this Eastern Branch empties the water of Washington Channel, an arti-

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[1] *Kofoid.* Loc. cit.

ficial waterway about 1 mile long and 200 yards wide, along which are the wharves and the shipping.

Some little sewage and a large amount of storm water empty into the Eastern Branch. In Washington Channel several large river steamers and a multitude of smaller craft will be sufficient guarantee for the entrance into the river of some waste material, including fecal matter. A number of fish markets and oyster wharves along this water front will in their season add to the contaminating material in the water of this channel.

The upper part of the 5-mile interval between Three Sisters and Giesboro Point receives the water of the Chesapeake & Ohio Canal, which is polluted by the addition of a considerable amount of sewage from Georgetown. A large storm-water sewer near the foot of Seventeenth Street, nearly a mile below the canal mouth, adds some polluting material after heavy rains or when streets have been scrubbed and flushed. In the lower 2 miles of the stretch on the Virginia side of the river and below the bridges is Fourmile Flat. A mile or more below Giesboro Point the sewage of Washington is pumped into mid-channel. The upstream movement of tidewater, asisted sometimes by a stiff breeze, is likely to carry sewage-polluted water from the sewer outlet to the sampling station at Giesboro Point.

Plankton samples.—August collections were taken on the 18th and the 26th of the month, both at a depth of 8 feet ("vertical samples"). The water was nearly clear, with temperatures of 25° and 26°, respectively. Both samples were taken at low tide.

The sample of August 18 showed (per liter) 9,000 diatoms, including 3,000 *Synedra*. Other genera present were *Epithemia*, *Gomphonema*, *Navicula*, *Stauronesis*, and *Stephanodiscus*. Filaments of blue-green algæ, chiefly *Oscillatoria*, amounted to 36,000 standard units. *Raphidium*, a minute one-celled green algæ, numbered 3,000. Animal life consisted of 1,000 *Difflugia*, 3,000 *Codonella*, together with a few specimens of another unidentified infusorian. The rotifer *Anuraea cochlearis* numbered 1,000 and *Cyclops* (a crustacean) a similar number.

The August 26 sample showed a similar plankton. Five genera of Diatomaceæ were present, *Synedra* again in the lead with 7,000 per liter in a total of 12,000 diatoms. Blue-green algæ were represented by *Gleocapsa* (2,000 per l.) and a small amount of *Oscillatoria*. *Eudorina* (3,000) and *Scenedesmus* (1,000) of the green algæ were present. *Crenothrix* completed the list of plants. Animals present were: *Difflugia* (2,000) *Tintinnus*, an infusorian, (1,000), and *Codonella* (2,000). Rotifers: *Anuraea cochlearis* (1,000) and *Asplanchna* (1,000) completed the list.

In September samples were taken on the 9th and the 18th. The tide was low or ebbing, and the water was nearly clear in each case. Diatoms were not numerous in either samples—6,500 per liter in the first and 4,000 in the second. However, the September 9 sample contained six genera, *Cocconema*, with 1,100 being in the lead. The second sample contained five genera, *Synedra* being by far the most abundant.

Filaments of *Oscillatoria* persisted in both samples. Another blue-green alga, *Clathrocystis*, appeared in the September 9 sample to the amount of 11,250 standard units per liter. In this same sample the minute green algæ *Eudorina* (750), *Scenedesmus* (1,500), *Protococcus* (5,625), *Polyedrium* (4,870), and *Staurastrum* (750) aggregated 13,500 per liter. These organisms were not found in the September 18 sample. *Crenothrix* was present in small amount in the first sample, and mold hyphæ in the second. Mastigophora (*Trachelomonas* and *Euglena viridis*) numbered 3,400 per liter in the first sample, but were absent in the second. Infusoria present in the first sample were *Codonella* (1,125), *Vorticella* (750), and *Halteria* (1,500); but only *Codonella* (1,000 per liter) appeared in the second sample. The rotifers *Colurus* (750), *Anuraea* (375), *Asplanchna* (300), *Brachionus* (1,900), and *Triarthra* (1,200), were in the first sample in the numbers (per liter) indicated. *Colurus* (250), *Anuraea* (770), and *Diglena* (240) were found in the second. A few crustaceæ (*Cyclops*) appeared in each sample, a few specimens of *Bosmina* were also found in the second. Nematode worms were in both samples, but they were not abundant.

The biological conditions just stated show evidence that the water is contaminated to some degree. The *persistence* of the blue-green algæ, together with their amount, indicates the admixture of a water that is distinctly more polluted than is the water at Three Sisters. This evidence is strengthened by the presence of *Trachelomonas* and *Euglena viridis* in one sample in moderate numbers, as both of these organisms, the latter especially, are characteristic of contaminated water. Consistent with these findings is the presence, in three of the four samples, of certain infusoria (*Tintinnus*, *Vorticella*, and *Halteria*) which normally live in water containing much organic matter. Finally, the number and variety of Rotifera (one sample yielding five genera) would seem to indicate the presence of their food supply, which consists largely of *Euglena*, ciliata, and microscopic algæ. (Kofoid, 1908.) These organisms are, in turn, dependent largely on a water rich in organic material. Several eminent investigators[1] are

[1] Drown, Jour. New England Waterworks Assn., 1888–90; Kofoid, Bull. Illinois Laboratory Nat. Hist., Vol. VIII, 1908, p. 24; Marsson, translation of lecture in Engineering News, Aug. 31, 1911.

of the opinion that certain algæ may absorb as food a portion of the organic matter directly from the water and that such organic matter in water greatly encourages the growth of these organisms. If this be true, the presence of five genera of the simple microscopic algæ in the sample taken September 9 would seem reasonable evidence of the presence of a considerable amount of organic matter in the water.

November plankton showed 9,000 diatoms per liter, of which 4,200 were *Melosira* and 1,800 were *Surirella*. Other genera present were *Pleurosigma*, *Navicula*, and *Synedra*. A small amount of the green alga *Desmidium* was found, and a few filaments of *Crenothrix*.

About 600 *Cyclops*, mostly young, were present. No Flagellates, Ciliates, or Rotifers were found.

A sample collected January 15, 1914, contained 26,000 diatoms per liter, composed of *Synedra lanceolata* (10,000), *Synedra biceps* (5,600), *Navicula* (2,800) *Surirella* and *Gomphonema* (about 1,200 of each). A small amount of the blue-green *Oscillatoria* was present. Green algae were represented by Closterium (1,200) and a fragment of *Chætophora elegans*. A small amount of mold hyphae, the infusorian *Codonella* (400) and a few specimens of *Anguillula*, a minute worm, completed the list.

Samples collected March 31, April 11, and May 14 (1914), were noted chiefly for the large number of diatoms. The March sample contained about 10,000 each of *Synedra*, *Melosira*, and *Synedra biceps*, 4,000 *Navicula* and a similar number of *Meridion circulare*. A few specimens of Stephanodiscus were present. The April sample contained *Synedra* (25,000), *Asterionella* (81,000), *Navicula* (9,000), *Synedra biceps* (5,000), and a few *Cocconema*. The sample taken in May yielded (per liter) 8,000 *Synedra*, 10,000 *Melosira*, and a few of other genera, including *Nitzschia longissima*. No blue-green algea were found in any of the samples. *Crenothrix* appeared in the April sample. A few rotifers (*Anuraea*) were found in the May sample, and *Cyclops*, chiefly young, were in the March sample. All samples contained a few plant hairs, fragments of plant epidermis, bits of hair (from animals), and of vegetable tissue.

The plankton content of these five samples taken in November, January, March, April, and May, respectively, indicate only moderately clean water. In connection with this statement it should be noted, however, that the temperature in November (11°) January (0°) March (10.5°) and April (10°) would check bacterial action to a great extent, hence would deplete or remove the main food supply of certain bacteria-eating Infusoria and Rhizopods, whose presence is regarded as an indication of unclean water. This, however, would not apply to the sample taken in May, as the temperature of this sample was 19.5°.

Bottom samples.—Mud samples scooped from the bottom of the channel of river in May consisted of mingled mud and sand. There was practically no odor, or a very slight one. In a plate of about 200 c. c. of mud there were found 19 tubificid worms, *Limnodrilus*, 2 young mussels, and 1 snail (*Planorbis*). Another sample, taken two weeks later, contained 71 worms and 2 *Chironomus* larvae. No living plants were found, the depth of the water here being about 30 feet.

FORT FOOTE.

This is 6 miles below Giesboro Point and 4½ miles below the point where Washington sewage is pumped into the river. Alexandria (15,000 population) is 2 miles above Fort Foote. This town has open sewers, and the sewage finds its way into the river, some of it draining in directly along the river front and some by a roundabout way through Hunting Creek Flat. The river is constricted at Fort Foote to the width of a half mile. Just above are two large expansions—Oxon Flat, with an area of about 1½ square miles, and Hunting Creek Flat, having an area of 1⅓ square miles. The water at Fort Foote is accordingly affected by the sewage of Washington and Alexandria, and by the two large flats, the tides insuring a mixing of all, water from flats, sewage, and channel water. While the sewage contamination is comparatively recent, as to distance, in point of time it may or may not be recent. At a certain stage of ebb tide and during certain months a water sample taken at Fort Foote will contain comparatively fresh sewage, having come, with little interruption by tides, direct from the place of discharge 4½ miles above. However, the same sample will contain the drainage of the flats, water and sewage which a previous flood tide has spread out on them, and which has been subject to such sedimentation, aeration, and general readjustment and biological action as the flats afford at that particular season. Again, a sample taken during flood tide will contain little or none of the sewage direct from the outlet above. Manifestly, the time of collecting (as to tides) will affect the chemical and particularly the biological content of the sample, the latter being very largely a question of the food supply found in organic matter of the water, together with the requisite time necessary for the breeding of those microscopic organisms collectively termed the plankton.

Samples were taken at this station usually in mid-channel every month, except January and February, from August to May, 1914. As many as four samples were taken during some months.

Environmental factors affecting aquatic life at this point are, in brief, the following:

1. Sewage from Washington pumped into the river 4½ miles above.
2. Tides, checking the current, reversing the flow, and mixing the waters.

3. Flats comprising an area of $2\frac{3}{4}$ square miles between this station and the sewer.
4. Spreading of sewage-rich water on these flats by flood tide, and return of water to river channel at ebb tide.
5. Submerged plant life on the flats during the summer and consequent physical, chemical, and biological effects on the water.
6. The "time factor" accruing to the water and its organisms because of the tides, the flats, and the plants on the flats.

The time factor.—It should be noted that, on account of the tides, the sewage may not flow directly down river from the sewer outlet. A float, placed in the water at the sewer during high tide passed and repassed this point five times. As it slowly made its intermittent progress downstream, it was turned back temporarily by each flood tide, or was carried to the edge of the flat as the flood-tide water sought the path of least resistance by spreading out on the flat. Many hours elapsed before the float reached this sampling station at Fort Foote, only $4\frac{1}{2}$ miles from its starting point. Had the float been able to follow the entire course of the water, as it spread out on the shallow flat and crept through the maze of aquatic plants, it would probably have been many days, instead of hours, in reaching Fort Foote.

The large time factor thus introduced and the thorough mixing of the sewage with a very large body of well-oxygenated water on the flats constitute the chief agencies affecting the water at this point. These conditions are reflected to some extent in the plankton content of the water.

If distance alone were considered, a large number of sewage organisms might be expected in the water only $4\frac{1}{2}$ miles below the sewer. Such, however, is not the case. It remains to be seen whether or not this unexpected condition is a result of the time factor introduced by the tides, increased by the flats, and emphasized, extended, and enforced by the submerged vegetation.

To the organisms normally in the water the greatly lengthened time factor means opportunity for activity. This activity is along two lines—(1) the securing of food; (2) reproduction. Quiescent water affords suitable conditions for reproduction. The ensuing activity consists chiefly of "eating or being eaten." The smaller forms, consuming minute algæ or perhaps bacteria, are themselves consumed by the larger animal forms, whose size compensates for the great number of their victims. It is, indeed, a "struggle for existence." The "fittest," usually the largest and strongest, survive, possibly to be eaten by young fish, whose food consists largely of these organisms. Some of these fish, surviving the cannibalistic habits of their fellows, may reach maturity and become food for man. Thus with endless variations and many interruptions the transfer of organic matter goes on in the water, forming a food cycle, or a "chain

of food relations," as aptly termed by Kofoid,[1] the various organisms concerned forming the links of the chain. It is the aquatic version of the food cycle, so familiar to all, wherein the land plant, nourished by inorganic food materials, becomes the food supply of worms or insects. These are devoured by birds or fowls, which in turn are eaten by larger animals, including man.

Plankton samples.—These were taken in midchannel every month from August to May, inclusive, except January and February, 1914. Twenty-four samples were taken in all. Because of the various factors affecting the water at this point, a relatively large number of samples were taken in order to secure a true picture of the average condition of the water.

August collections showed the following per liter: Diatoms 34,000, chiefly *Synedra* and *Navicula;* filaments of Oscillatoria 20,000 standard units, a small amount of *Spirogyra*, and 2,000 *Eudorina* appeared in one sample. *Raphidium* (2,500), *Scenedesmus* (1,000) and *Staurastrum* (1,000) completed the green algæ, except 21,000 standard units of the green alga *Ulothrix*, which was found in one sample. Both samples contained the Rhizopod *Difflugia*, 1,000, and 2,000 per liter, respectively, and one sample showed 5,000 standard units of mold hyphæ. Mastigophora were represented in one sample by 1,000 *Euglena*, and in the other by a similar number of *Phacus*. Of the Infusoria, there were 3,000 *Carchesium* per liter, and 7,000 *Codonella* in one sample and 3,000 in the other. Rotifers were present in both. *Anuraea cochlearis* (1,000 in each) and *Rotifer vulgaris* (1,000) in one. The crustaceans, *Bosmina* and *Cyclops*, about 1,000 each, appeared in one sample. *Cyclops* alone were found in the others. The majority of the cyclops were young. A few specimens of the minute worm *Anguillula* were present in one sample.

The presence of sewage in the water is indicated by the Molds, Rhizopods, Mastigophora, and Infusoria, especially the latter two. *Rotifer tardus* exhibits a decided preference for contaminated water. While these organisms are not present in large numbers, their moderate abundance, together with the variety of forms represented, bear reasonable testimony that sewage is not absent.

September collections showed essentially the same conditions. *Carchesium*, *Euglena*, and *Rotifer tardus* were not found, but *Phacus* and *Trachelomonas*, of the Mastigophora, and *Tintinnus* and *Epistylis*, of the Infusoria, furnished reasonable evidence of contamination.

In October samples the presence of "contaminate" organisms was less noticeable, and the evidence of pollution so far as plankton or-

[1] Bull. Illinois State Laboratory Nat. Hist., Vol. VI, Art. II, p. 535.

ganisms were concerned, was at best doubtful. Certain forms, notably the Mastigophora and the Rotifera, decreased in abundance with the gradual advent of cool weather in October and November. Winter conditions, including much ice on the river, persisted until late in the spring, and probably had much to do with the delay of bacterial action in the water, the temperature of which was 9.5° as late as April 11, 1914. It is supposed (though as yet unproven) that the bacteria engaged in the destruction of organic material constitute the principal food supply of the Mastigophora and Infusoria, hence cold weather would tend to cut off this food supply by checking bacterial activity.

A sample taken May 4 shows the presence of *Trachelomonas* (Mastigophora) and Colpidium (an Infusorian). The latter organism, especially, is characteristic of impure water. Temperature of the water at this time was 18°. Subsequent samples taken in this month contained Mastigophora, Infusoria, Rotifera, and Crustacea, consistently increasing in number and variety until our last sample, taken May 25, when the temperature was 23°.

Bottom samples.—Mud samples, obtained in May from mid-channel at a depth of 35 feet, contained considerable vegetable débris, leaf fragments, etc., were very dark in color, and had a trace of sewage odor. No plants except a small amount of *Oscillatoria* were found in the mud.

The animal population was distinctly indicative of contaminated or polluted water. An average of 79 Tubificidae or "sewage worms" per plate (200 c. c. of mud) with a few *Chironomus* larvæ and young mussels (the latter in two samples only) were found. No may-fly larvæ, leeches, or unios (mussels) were seen, although these forms were fairly abundant in the adjacent flat.

Mud samples taken 500 feet below the sewer, together with the samples taken from the river channel 2 miles above Fort Foote, show counts consistent with those already mentioned.

Tubificid worms are very numerous just below the sewer, there being 1,000 or more per plate. Two miles above Fort Foote and 2½ miles below the sewer the number decreased to about 620, of which a part were possibly due to Alexandria sewage.

Reference to Table 27 will show that these curious organisms decrease consistently in number down the river, as the distance from the sewer increases. There is corresponding improvement in the odor of the mud also. It is probable that this worm is, in itself, a valuable index of the condition of the water.

TABLE 27.—*Decrease of tubificid worms in mud from channel below sewage outlet.*

Location.	Distance below sewer.	Average number of tubificid worms in 200 c. c. mud.	Character of mud.		
			Color.	Odor.	Consistency.
Near sewer....................feet..	500	(1)	Very dark.	Foul, like sewage.	Soft; a little sand.
Opposite Alexandria.........miles..	2½	620	Dark......	Strong, unpleasant.	Granular; some sand.
Fort Foote....................do....	4½	79	...do......	Some odor of sewage.	Soft to heavy silt; granular clay.
Fort Washington.............do....	12	37	Dark to yellow.	Slight unpleasant odor.	Sticky to granular.
Whitestone Point.............do....	14	14	...do......	Very slight	Granular, clay.
Indianhead....................do....	20	8	Yellow....	Slight.....	Granular, sandy.
Possum Point.................do....	26	2	Yellow to dark.	...do......	Soft, clay, granular.
Maryland Point...............do....	40	(2)	...do......	...do......	Soft, granular.
Popes Creek...................do....	51	1	Yellow....	None......	Soft, clay.
Lower Cedar Point...........do....	55	1	...do......	...do......	Fine, soft, granular.
Colonial Beach...............do....	62	0	Yellow to dark.	...do......	Soft, clay.
Giesboro Point (above sewer)........	....	19	Yellow to gray.	Slight.....	Sandy.
Anacostia River, or Eastern Branch (above sewer).	....	6	Dark......	Sewage odor.	Fine, sticky, soft.
Foot of Seventeenth Street (above sewer).	....	2	....	....	
Below storm-water sewer, near Seventeenth Street (above sewer).	....	20	....	....	

[1] Very numerous; over 1,000. [2] In 1 sample.

TABLE 28.—*Plankton data, Potomac River.*

THREE SISTERS STATION.

Number of sample.	Date.	Hour.	Surface.	Temperature of water (centigrade).	Turbidity.	Depth of water (feet).	Depth of sample (vertical section) (feet).	Tide. Ebb.	Tide. Flood.	Amount of sample (liters).	Amount of catch (c. c.).	Percentage of plankton.	Volume of plankton per m³ of water (c. c.).	Volume of amorphous matter and silt per m³ water (c. c.).	Total catch per m³ of water (c. c.).	Remarks.
	1913.															
3	July 31	12.45 m.	Smooth	28	12	25	8		Flood.	4	0.05					Dark clouds following shower.
10	Aug. 9	12.45 m.	Ripples	27	15	25	8		do.	4	.06	2.34	0.36	14.64	15.00	Dark clouds.
14	Aug. 12	12.45 m.	do.	26	40	25	8	Ebb.		4	.07					Sunshine.
23	Aug. 18	1.20 p. m.	do.	26.5	28	25	8	do.		4	.04	2.27	.23	9.77	10.00	Breeze; sunshine.
28	Aug. 20		do.	27	19	25	8	do.		4	.05	4.29	.54	11.96	12.50	Sunshine.
35	Aug. 26	12.45 m.	Smooth	26.5	19	25	8	Low.		4	.05	2.81	.35	12.15	12.50	Do.
43	Sept. 2	2 p. m.	Ripples	26	70	25	8	Ebb.		4	.05					Cloudless; light breeze.
51	Sept. 9	1.20 p. m.	do.	26.5	17	25	8		Half.	4	.05	10.3	1.29	11.21	12.50	Dark overcast; light breeze.
60	Sept. 17	1.45 p. m.	do.	21.5	10	25	8		Low.	4	.07	1.89	.33	17.17	17.50	Sunshine; hazy clouds.
71	Sept. 30	1.30 p. m.	Light swell	21.5	28	25	8		do.	3¼	.04	4.46	.55	11.76	12.31	Cloudless; breeze.
84	Oct. 16	1 p. m.	Swell	16	40	25	18		do.	2	.08	1.46	.58	39.42	40.00	Overcast; breeze.
88	Oct. 21	12.15 p. m.	do.	14	26	25	25		High.	4	.09	1.76	.40	22.10	22.50	Sunshine; breeze.
95	Nov. 4	2.20 p. m.	Swell and waves.	11	55	25	20	Ebb.		3	.08	1.25	.33	26.34	26.67	
103	Nov. 18	1 p. m.	Smooth	8	150	25	20	High.		2	.25	2.05	2.56	122.44	125.00	Sunshine; water muddy; breeze.
109	Nov. 25	1 p. m.	do.	10	45	25	20	do.		4	.10	6.01	1.50	23.50	25.00	Overcast; plants floating.
	1914.															
146	Mar. 31	1.30 p. m.	Small waves	10.5	45	25	9	Half.		2	.14	4.78	3.35	66.65	70.00	Partial overcast; breeze.
151	Apr. 13	2 p. m.	do.				8	Low.		4	.12	5.77	1.73	28.27	30.00	Cloudless; light breeze.
	Average												1.00			

GIESBORO POINT STATION.

	1913.														
18	Aug. 13	12 m......	Ripples.....	25.5	40	38	8	Low...	....	4	0.07	5.45	.95	16.55	17.50	Dark clouds.
22	Aug. 18	12 m	.....do.......	26	....	38	8	...do...	....	4	.05	12.41	1.55	10.95	12.50	Sunshine; light swell.
34	Aug. 26	12 m......	Small waves	25	11	38	8	....	Low..	4	.10	5.79	1.45	23.55	25.00	Sunshine; breeze.
46	Sept. 3	1.15.......	.....do......	26	22	38	8	....	....	4	.08	....	....	....	....	Partial overcast.
48	Sept. 9	9 a. m.....	.....do......	26	15	38	8	....	Low..	4	.09	6.23	1.40	21.10	22.50	Cloudless; light breeze.
64	Sept. 18	1 p. m.....	Waves and swell.	22	10	38	8	Ebb ..	....	4	.09	5.01	1.13	21.37	22.50	Overcast.
94	Oct. 4	1.30 p. m..	.....do......	11	50	38	35	...do..	....	2	.05	7.24	1.81	23.19	25.00	Sunshine; breeze.
	1914.															
133	Jan. 15	10.30 a. m.	Floating ice.	0	100	38	35	....	....	3	.08	5.12	1.37	25.29	26.66	Overcast; calm; cold.
135	Jan. 22	10 a. m....	Thin ice.....	1	50	38	37	Ebb ..	....	4	.11	2.19	.60	26.90	27.50	Partial overcast.
141	Mar. 16	1 p. m.....	....	5	80	38	25	High..	....	....	.04	....	....	....	....	
145	Mar. 31	1 p. m.....	Small waves	10.5	35	38	9	...do..	....	2	.08	3.59	1.44	38.56	40.00	
150	Apr. 11	1.40 p. m..	Rough......	....	....	38	8	....	Low..	3	.10	3.46	1.15	32.18	33.33	
162	May 14	10.30 p. m.	Smooth.....	19.5	....	38	7	....	Half..	4	.12	2.63	.79	29.21	30.00	
	Average........												1.24			

TABLE 28.—*Plankton data, Potomac River*—Continued.

FORT FOOTE STATION.

Number of sample.	Date.	Hour.	Surface.	Temperature of water (centigrade).	Turbidity.	Depth of water (feet).	Depth of sample (vertical section) (feet).	Tide.		Amount of sample (liters).	Amount of catch (c. c.).	Percentage of plankton.	Volume of plankton per m³ of water (c. c.).	Volume of amorphous matter and silt per m³ water (c. c.).	Total catch per m³ of water (c. c.).	Remarks.
								Ebb.	Flood.							
	1913.															
13	Aug. 12	11 a. m.		26		45	8	Ebb		4	0.10	9.37	2.34	22.66	25.00	Raining.
20	Aug. 18	10 a. m.	Ripples	26	17	45	8	do		4	.10					Dark overcast.
24	Aug. 19	9.45 a. m.	do	26	18	45	8	do		4	.09					Sunshine.
32	Aug. 26	9.40 a. m.	Waves	25	13	45	8		Low	4	.10	7.49	1.87	23.13	25.00	Sunshine and breeze.
40	Sept. 2	9.45 a. m.	Small waves	26	17	45	8		High	4	.08	4.40	.88	19.12	20.00	Sunshine; staminate flowers of eel grass floating.
49	Sept. 9	9.40 a. m.	do	26	11	45	8	Low		4	.09	3.40	.77	21.73	22.50	Cloudless; light breeze.
62	Sept. 18	9.45 a. m.	Waves and swell.	21.5	18		8		High	4	.17	3.43	1.46	41.05	42.50	Dark overcast; light rain; breeze.
69	Sept. 30	9.30 a. m.	Light swell	20	26	45	8		do	4	.13	3.17	1.03	31.47	32.50	Cloudless; calm.
72	Oct. 7	9.45 a. m.	do	19	45	45	35	Low		4	.15	5.54	2.08	35.42	37.50	Dark overcast; calm.
73	do	9.45 a. m.	do	19	45	45	35	do		4	.18	3.80	1.71	43.29	45.00	Do.
81	Oct. 16	9.30 a. m.	Calm	17	20	45	35		High	4	.11	7.79	2.14	25.36	27.50	Cloudless; vegetation floating.
87	Oct. 21	11 a. m.	Small waves	15	26	45	40		do	4	.09	6.71	1.51	20.99	22.50	Overcast; breeze.
92	Nov. 4	11 a. m.	Waves and swell.	11	80	45	35		do	2	.08	7.85	3.14	36.86	40.00	Sunshine; breeze.
101	Nov. 18	9.45 a. m.	Calm	7	120	45	40		do	4	.10	5.58	1.40	23.60	25.00	Do.
107	Nov. 25	9.45 a. m.	do	10	90	45	35	Low		4	.10	3.59	.90	24.10	25.00	Do.
113	Dec. 5	12.30 a. m.	Waves	10.5	35	45	40		High	4	.17	2.09	.89	41.61	42.50	Do.
	1914.															
139	Mar. 16	10 a. m.	Calm	3.5	60	45	35			3	.04	8.35	1.11	12.22	13.33	Sunshine; calm.
143	Mar. 31	10 a. m.	Waves	10.5	30	45	40		Half	3	.07	5.80	1.35	21.98	23.33	Partial overcast; breeze.
148	Apr. 11	10 a. m.	Rough	9.5	30	45	8	Half		4	.06	5.91	.89	14.11	15.00	Light overcast; stiff breeze; "white caps."
153	May 4	3 p. m.	Smooth	18	24		8	do		2	.10	1.57	.79	49.21	50.00	Sunshine; débris floating.
163	May 14	11 a. m.	Small waves	20		45	8			4	.07	6.16	1.08	16.42	17.50	Sunshine; light breeze.
165	May 19	9.15 a. m.	Waves	20.5		45	8		Low	4	.15	2.40	.90	36.60	37.50	Do.
185	May 26	9.30 a. m.		23	30	45	8	Half		4	.10	4.12	1.03	23.97	25.00	
	Average												1.35			

	1913.															
1	July 31	10.30 a. m.	Smooth	27	20	38	8	Half		4	0.18	9.75	4.43	40.57	45.00	Floating débris.
8	Aug. 9	9.45 a. m.	do	27.5	17	38	8		Flood.	4	.11	5.30	1.46	26.04	27.50	Partial overcast.
12	Aug. 12	10 a. m.	Rain	26	17	38	8	Ebb		4	.18	8.89	4.00	41.00	45.00	Hard rain.
21	Aug. 18	10.30 a. m.	Ripples	26	20	38	8	do		4	.10					Sunshine.
25	Aug. 19	10.30 a. m.	Waves	26	30	38	8	do		4	.10					Do.
33	Aug. 26	9.40 a. m.	Small waves	25	17	38	8		Low	4	.10	5.43	1.36	23.64	25.00	Sunshine; breeze.
41	Sept. 2	10.45 a. m.	Ripples	27	28	38	8		High	4	.10					Sunshine.
50	Sept. 9	10.40 a. m.	Waves and swell.	26	22	38	8	Low		4	.09	9.44	2.12	20.38	22.50	Clouds; stiff breeze.
63	Sept. 18	10.45 a. m.	do	22	40	38	8	High		4	.13	5.10	1.66	30.84	32.50	Overcast; light rain.
70	Sept. 30	10.30 a. m.	Swell	21	30	38	8	do		4	.30	2.77	2.08	72.92	75.00	Cloudless; calm.
74	Oct. 7	11 a. m.	do	19	80	38	25		Half	3¼	.25	5.30	4.08	72.92	77.00	Dark overcast; breeze.
75	do	11 a. m.	do	19	75	38	25		do	4	.27	4.48	3.02	64.48	67.50	Do.
82	Oct. 16	10.30 a. m.	Small waves	18	28	38	24		High	3½	.28	3.08	2.46	77.54	80.00	Cloudless; breeze; floating vegetation.
93	Nov. 4	11.40 a. m.	do	12	140	38	25		do	2	.07	6.92	2.42	32.58	35.00	Sunshine; breeze.
102	Nov. 18	10.30 a. m.	do	7	100	38	30		do	2	.10	2.16	1.08	48.92	50.00	Do.
108	Nov. 25	10.35 a. m.	do	10	110	38	20	Low		4	.10	5.56	1.39	23.61	25.00	Do.
114	Dec. 5	1.30 p. m.	Waves and swell.	10	40	38	30		High	4	.09	2.42	.54	21.96	22.50	Do.
	1914.															
140	Mar. 16	11 a. m.	Smooth	3	60	38	35			4	.05	11.33	1.42	11.08	12.50	
144	Mar. 31	11 a. m.	Small waves	11	30	38	9		High	4	.06	9.28	1.39	13.61	15.00	Light breeze.
149	Apr. 11	11 a. m.	Rough	11.5	100	38	8	High		3	.18	1.90	1.14	58.86	60.00	Sunshine; stiff breeze; "white caps."
164	May 14	12.30 p. m.	Small waves	20		38	8	Half		4	.12	3.52	1.06	28.94	30.00	Sunshine; light breeze.
	Average												2.06			

TABLE 28.—*Plankton data, Potomac River*—Continued.

DISTRICT I.—ESTUARY POTOMAC STATION.

Number of sample.	Date.	Hour.	Surface.	Temperature of water (centigrade).	Turbidity.	Depth of water (feet).	Depth of sample (vertical section) (feet).	Tide. Ebb.	Tide. Flood.	Amount of sample (liters).	Amount of catch (c. c.).	Percentage of plankton.	Volume of plankton per m³ of water (c. c.).	Volume of amorphous matter and silt per m³ water (c. c.).	Total catch per m³ of water (c. c.).	Remarks.
	1913.															
117	Dec. 16	3 p. m.	Small waves.	7	28	30	25		Low	4	0.10	4.81	1.20	23.80	25.00	Sunshine; breeze (Liverpool Point).
128	Dec. 18	12.30 p. m.	Waves and swell.	6.5	60	30	25	High		4	.10	13.77	3.44	21.56	25.00	Cloudless.
118	Dec. 16	4 p. m.	Small waves.	7	18	50	40	Low		4	.25	5.13	3.21	59.29	62.50	Partial overcast (Maryland Point).
127	Dec. 18	11.30 a. m.	Rough	7	35	50	45		High	4	.18	9.70	4.37	40.63	45.00	Cloudless (Maryland Point).
	1914.															
155	May 7	3 p. m.		19	80	50	45	Low		2	.05	9.89	2.47	22.53	25.00	Do.
178	May 22	9.45 a. m.	Smooth	21.5	50	50	7	Half		2	.08	5.20	2.08	37.92	40.00	Sunshine; calm (Maryland Point).
	1913.															
119	Dec. 16	5.30 p. m.	Calm	8	24	48	45	Low		4	.43	3.17	3.41	104.09	107.50	Calm (Popes Creek).
126	Dec. 18	10.15 a. m.	Small waves.	8	15	48	45		High	4	.25	2.94	1.84	60.66	62.50	Cloudless; breeze (Popes Creek).
	1914.															
156	May 7	5 p. m.		18	25	48	8		Half	4	.05	24.17	3.02	9.48	12.50	Sunshine (Popes Creek).
177	May 22	9 a. m.	Smooth	20	12	48	8	Half		2	.05	13.53	3.38	21.62	25.00	Sunshine; calm (Popes Creek).
157	May 7	6 p. m.	do			48	8	High		4	.08	4.22	.84	19.16	20.00	Sunshine; breeze (Lower Cedar).
	Average												2.66			

DISTRICT II.—ESTUARY POTOMAC STATION.

Number of sample.	Date.	Hour.	Surface.	Temperature of water (centigrade).	Turbidity.	Depth of water (feet).	Depth of sample (vertical section) (feet).	Tide. Ebb.	Tide. Flood.	Amount of sample (liters).	Amount of catch (c. c.).	Percentage of plankton.	Volume of plankton per m³ of water (c. c.).	Volume of amorphous matter and silt per m³ water (c. c.).	Total catch per m³ of water (c. c.).	Remarks.
	1913.															
120	Dec. 17	9.45 a. m.	Calm	8	7	50	45		High	4	0.10	12.55	3.14	21.86	25.00	Sunshine; breeze (Blakistons Island).
	1914.															
129	Jan. 13	9.45 a. m.	Small waves.	2	40	50	30		do	3	.16	8.73	4.66	48.67	53.33	Do.
169	May 19	6 p. m.	Calm	21	9	50	8			4	.04	11.59	1.16	8.84	10.00	Sunshine; calm (Blakistons Island).
175	May 21	11.20 a. m.	do	22.5	8	30	8			4	.16	4.88	1.95	38.05	40.00	Cloudless; calm (St. Clements Bay).
174	do	10 a. m.	do	22.5	8	30	8			4	.09	14.72	3.31	19.19	22.50	Cloudless; calm (Bretons Bay).

DISTRICT III.—ESTUARY POTOMAC STATION.

	1913.															
125	Dec. 17	3.30 p. m. .	Calm........	8	7	30	25	....	Low. .	4	0.18	14.51	6.53	38.47	45.00	Light overcast (Ragged Point).
122	...do	12 m......	.....do.......	8	7	20	10	....	High. .	4	.09	26.8	6.03	16.47	22.50	Light overcast (St. Georges Island).
	1914.															
170	May 20	8.15 a. m. .	Waves......	19.5	8	28	8	....	....	4	.04	12.04	1.20	8.80	10.00	Sunshine; breeze (Priests Point).
131	Jan. 13	2 p. m.....	Small waves.	2	12	38	30	Half...	....	3	.05	9.9	1.65	15.02	16.67	Sunshine; light breeze (St. Marys River).
130	Jan. 13	1.30 p. m. .	.....do.......	2	12	20	15	...do...	....	3	.07	10.43	2.43	20.90	23.33	Do.

DISTRICT IV.—ESTUARY POTOMAC STATION.

	1913.															
123	Dec. 17	1.30 p. m. .	Calm........	8.5	7	16	13	Half...	....	4	0.09	52.83	11.89	10.61	22.50	Sunshine (Point Lookout).
124	...do	2.15 p. m. .	.....do.......	8	7	35	30	...do...	....	4	.15	20.62	7.73	29.77	37.50	Do.

Average for Districts II, III, and IV, 4.31 c. c. plankton per m^3 of water.

HUNTING CREEK FLAT, STATION F.

	1913.															
6	Aug. 6	10.45 a. m.	Smooth.....	28	8	5	4	....	High. .	4	0.10	....	....	....	....	Cloudy; eel grass abundant.
16	Aug. 13	10.45 a. m.	.....do.......	23	12	4	3	Half...	....	4	.10	6.17	1.54	23.46	25.00	Dark overcast; eel grass abundant.
31	Aug. 21	10.45 a. m.	.....do.......	25	8	5	4	....	High. .	4	.10	25.34	6.34	18.66	25.00	Partial overcast; eel grass abundant.
37	Aug. 27	10.45 a. m.	.....do.......	25	7	3	2	Low. .	....	4	.08	....	....	....	....	Sunshine; eel grass abundant.
45	Sept. 3	11.30 a. m.	.....do.......	26	11	4	3	Half...	....	4	.10	36.19	9.05	15.95	25.00	Sky overcast; breeze; eel grass abundant.
53	Sept. 10	11 a. m....	.....do.......	21	8	4	3	....	Low. .	4	.05	27.00	3.37	9.13	12.50	Sunshine; eel grass abundant.
58	Sept. 17	11 a. m....	.....do.......	21	6	5½	5	....	High. .	4	.09	....	....	....	....	Dark overcast; calm; eel grass abundant.
66	Sept. 24	11 a. m....	.....do.......	18	7	4	3	Half...	....	4	.04	32.20	3.23	6.77	10.00	Sunshine; calm; eel grass abundant.
78	Oct. 8	11 a. m....	.....do.......	19.5	9	5	4	....	Half...	4	.08	6.51	1.30	18.70	20.00	Dark overcast; calm; eel grass abundant.
79	Oct. 15	11 a. m....	.....do.......	18	12	4	3	....	...do...	4	.05	11.17	1.40	11.10	12.50	Light overcast; calm; eel grass abundant.
184	May 26	4 p. m.....	.....do.......	28	30	2½	1½	Low. .	....	2	.10	3.04	1.52	48.48	50.00	Sunshine; potamogeton abundant.
	Average........												3.46			

TABLE 28.—*Plankton data, Potomac River*—Continued.

HUNTING CREEK FLAT, STATION G.

Number of sample.	Date.	Hour.	Surface.	Temperature of water (centigrade).	Turbidity.	Depth of water (feet).	Depth of sample (vertical section) (feet).	Tide. Ebb.	Tide. Flood.	Amount of sample (liters).	Amount of catch (c. c.).	Percentage of plankton.	Volume of plankton per m^3 of water (c. c.).	Volume of amorphous matter and silt per m^3 water (c. c.).	Total catch per m^3 of water (c. c.).	Remarks.
	1913.															
5	Aug. 6	10.30 a. m.	Smooth	27	9	8	7	....	High	3	0.05	46.86	7.81	8.86	16.67	Cloudy; much eel grass, etc., present.
15	Aug. 13	10.30 a. m.	do	24	7	8	6	Half	....	4	.05	....	....	....	....	Dark overcast; much eel grass, etc., present.
30	Aug. 21	10.30 a. m.	do	25	9	8	7	....	Half	4	.08	17.80	3.56	16.44	20.00	Sunshine; much eel grass, etc., present.
36	Aug. 27	10.30 a. m.	do	25	7	6	4	Low	....	4	.11	....	....	....	....	Light overcast; much eel grass, etc., present.
54	Sept. 10	11 a. m.	do	23	8	6	5	....	Low	4	.09	21.58	4.86	17.64	22.50	Do.
57	Sept. 17	11 a. m.	do	21	6	6	6	....	High	4	.10	16.71	4.18	20.82	25.00	Dark overcast; calm; much eel grass, etc., present.
65	Sept. 24	10 a. m.	do	19	7	6	4	....	Low	4	....	....	....	....	....	Sunshine; much eel grass, etc., present.
77	Oct. 8	11 a. m.	do	19.5	12	6	4	Low	....	4	.08	10.82	2.16	17.84	20.00	Partial overcast; much eel grass, etc., present.
97	Nov. 5	4 p. m.	do	11	20	6	4	do	....	2	.08	13.11	5.24	34.76	40.00	Sunshine; much eel grass, etc., present.
111	Nov. 26	11 a. m.	do	8	35	6	3	do	....	4	.10	11.00	2.75	22.25	25.00	Dark overcast; spirogyra present.
183	May 26	3 p. m.	do	25	35	6	3	do	....	2	.08	7.34	2.94	37.06	40.00	Sunshine; very few plants.
	Average												4.19			

HUNTING CREEK FLAT, STATION M.

	1913.															
90	Oct. 22	5 p. m.	Smooth	13	12	5	4	Ebb		2	0.05	32.72	8.18	16.82	25.00	Sunshine; calm; eel grass, etc.
91	Oct. 29	10 a. m.	do	14.5	15	5	4	do		4	.09	11.82	2.66	19.84	22.50	Sunshine; most of flat very muddy.
96	Nov. 5	3 p. m.	do	11	24	5	4	do		2	.05	7.25	1.81	23.19	25.00	Sunshine; spirogyra on eel grass.
99	Nov. 12	10 a. m.	do	6	28	5	4	do		4	.07	6.87	1.20	16.30	17.50	Do.
110	Nov. 26	10 a. m.	do	9	40	5	4	do		2	.07	4.67	1.63	33.37	35.00	Overcast; calm; spirogyra on eel grass.
182	May 26	3 p. m.	do	25	35	5	4	do		2	.08	8.63	3.45	36.55	40.00	Sunshine; plants starting to grow.
	Average												3.15			

ANACOSTIA RIVER, OR EASTERN BRANCH, STATION.

	1913.															
11	Aug. 12	9 a. m.	Rain	27	....	25+	8	Ebb		4	0.08	6.24	1.25	18.75	20.00	Rain.
19	Aug. 18	9 a. m.	Quiet	25	17	25+	8	do		4	.06	11.68	1.75	13.25	15.00	Dark overcast after shower.
39	Sept. 2	9 a. m.	do	26	20	25+	8		High	4	.10	5.78	1.45	23.55	25.00	Sunshine.
61	Sept. 18	9 a. m.	Small waves	22	12	25+	8		do	4	.09	10.34	2.33	20.17	22.50	Diffused sunlight.
68	Sept. 30	9 a. m.	Calm	20	40	25+	8		do	4	.09	....	....	....	....	Diffused sunlight; vegetation floating.
80	Oct. 16	9 a. m.	do	17	22	25+	24		do	4	.10	2.33	.58	24.42	25.00	Cloudless; calm; vegetation floating.
98	Nov. 11	9 a. m.	Small waves	8	40	25+	18		do	4	.15	10.00	3.75	33.75	37.50	Half overcast; light breeze.
100	Nov. 18	9 a. m.	do	7	100	25+	25		do	3½	.12	....	....	....	....	Sunshine; floating débris.
106	Nov. 25	9 a. m.	do	10	45	25+	22	Low		4	.06	2.36	.35	14.65	15.00	Sunshine; slight breeze.
138	Mar. 16	9 a. m.	Quiet	4	70	25+	25			4	.09	7.65	1.72	20.78	22.50	Sunshine; calm.
142	Mar. 13	9 a. m.	Small waves	10.5	30	25+	9		Half	4	.08	2.54	.51	19.49	20.00	Partial overcast; breeze.
147	Apr. 11	9 a. m.	Rough	9	35	25+	8	Half		4	.06	6.35	.95	14.05	15.00	Partial overcast; stiff breeze.
	Average												1.46			

MOUNT VERNON AND MARSHALL HALL.

This station is 12 miles below the sewer outlet. In point of time, however, it is an average of about 4 days' distant, as shown by float experiments. The sewage and water below the mouth of sewer have been subject during this 4-day interval to the physical, chemical, and biological action incident to 16 tides; 8 flood tides have checked the current or turned it upstream and spread much of the channel water out on the flats; and 8 ebb tides have again reclaimed a portion of the water by partial drainage of the flats and shallows.

Between Mount Vernon and Fort Foote above are two large flats, together with a considerable area of marginal flats along the river channel. The approximate total area of flats to which the water is exposed in the 100-hour trip from sewer to Marshall Hall is 6.7 square miles,[1] or over 4,200 acres. This is exclusive of the channel proper.

Occasional samples, taken at Whitestone Point just below Marshall Hall, and at Indianhead, 6 miles below, represent similar conditions and will be included with the Marshall Hall samples.

Plankton samples.—Collections at this station give results so nearly like those of Fort Foote, 8 miles above, that a brief mention will be sufficient.

A considerable increase in the average number of diatoms over those at Fort Foote, together with a further decrease of those organisms which indicate contamination, seem to constitute the chief points of difference.

Two large flats are located between Fort Foote and Marshall Hall. Irrespective of these flats the average width of the river here is about 1 mile. We find here the same factors essentially as those that obtained at Fort Foote, with a substantial balance, however, in favor of better water because—(1) two additional flats serve as delay stations and oxygenating bases; (2) the time factor is increased to four days, not including the probable delay of several days on the flats where the float could not follow; and (3) the volume of water is greatly increased, hence there is greater dilution.

These changes in environment are consistently reflected in the improvement in the plankton content. Diatoms are abundant. Blue-greens are present in only 3 of the 15 samples. Mold hyphæ appear in two samples, Rhizopoda in four, and Mastigophora in two. The Infusoria (exclusive of the ever-present *Codonella* which, according to Kofoid, does not necessarily indicate the presence of polluting material), are present in four samples only.

Rotifer actinurus, a lover of contaminated water, appears in two samples, but other genera appear in eight samples.

[1] Approximated by writer from navigation chart of Potomac River.

Crustacea, chiefly *Cyclops*, appear in 10 samples, but in small numbers. This organism is a normal inhabitant of water of good quality as far as sewage is concerned. On the whole, the evidence furnished by the plankton as to the presence of sewage is almost negative.

Mud samples from this point, or a little below at Whitestone Point, show an average number of 12 tubificid worms in the same amount of mud that yielded 79 worms at Fort Foote. *Chironomus* larvæ were found (one specimen) in each of two samples. One sample showed a small amount of blue-green algæ. The mud had no offensive odor. It contained some small plant fragments, chiefly of forest leaves. According to this evidence of the mud, pollution is not absent, though present evidently in small amount only.

The plankton samples showed *Synedra* to be the most abundant in eight of the collections. The other leading genera were *Navicula*, *Cyclotella*, *Pleurosigma*, *Surirella*, and *Stephanodiscus*. *Gomphonema* was found in two samples, and *Nitzschia* appeared in one sample only. Various other genera appeared in some of the samples, but in small amounts only. In the sample of October 7 there were 12 genera represented in the total diatom count of 45,000.

STUDY OF THE FLATS.

Samples were taken on representative flats to secure data (1) as to plankton content and mud organisms, (2) as to dissolved gases, and (3) to determine what benefit or injury, if any, resulted to the water from the growth, activity, and decay of submerged plants. Incidental but important factors were (1) results of tidal action, (2) fate of sewage entering a plant-filled flat, (3) high turbidity caused by winds in absence of submerged plants, and (4) effects of sunlight on plant activity.

OXON FLAT.

Area, about 1½ square miles. Located opposite Alexandria, and 2½ miles below outlet of Washington sewer. This was intended to be a regular sampling point, but the activity of large dredges in the immediate vicinity necessitated abandoning this station in October.

HUNTING CREEK FLAT.

This flat was studied with care. It comprises an area of 1.3 square miles, with a river frontage of 1.25 miles extending from Jones Point Light, below Alexandria, to Smiths Point, opposite Fort Foote. The shores are only partially cleared, some brush and small trees covering the banks farthest from the river. A marsh of about 0.18 square mile in extent constitutes the extreme upper portion farthest from

the river. This marsh is thickly covered with various swamp plants, chiefly *Alisma* (water plantain), *Sagittarius* ("Arrow-head") various sedges, and great quantities of *Zizania aquatica* (wild rice or water oats), and other water grasses. The luxuriance of this marsh growth is easily understood when we consider the fertility of the swamp mud and the action of the tides by which the growing crop is alternately covered with water and exposed to air every six hours.

A country road bridges the extreme upper part of this flat, bordering the marsh just mentioned. About one-third mile farther toward the river a long bridge, supported on trestles and belonging to the Mount Vernon, Alexandria & Washington Electric Railway, is constructed across the flat. The water at this point is 3 to 6 feet deep at mean low tide. Approximately the same depths prevail over the entire flat from this bridge to the river channel. Three small runs empty into the upper part of the flat, two being polluted with sewage from Alexandria and smaller near-by towns. The mouths of these sewage-laden runs are marked P and R, respectively (see map No. 8). The one marked R discharges approximately 2½ to 3 cubic feet per second, while the other discharges about 4 to 5 cubic feet. The discharge from R varies considerably with the time of day and the day of week, being greatest in the mornings and especially on Monday (wash day). The water discharged has a foul odor, is grayish in color, and contains abundant evidence of its source in the shape of floating bits of toilet paper, masses of *Leptomitus*, a fungus usually found in sewage, and black, foul sludges in the bottom, from which much gas arises when it is disturbed.

The water in P is polluted to a less extent when it reaches the flat. This run contains sewage from one or two small suburban towns. Occasional floating masses of *Leptomitus*, together with certain blue-green algæ (especially *Oscillatoria*) and a green alga, *Coleochæte*, attest that its water is less polluted than that of R. The bottom mud of this larger run contains in certain quiet, shallow places great numbers of tubificid worms.

A small dredged channel ("Keystone") extends from the river proper into this flat a distance of a half mile or more. This channel, 30 feet wide at the mouth and 8 or 10 feet deep, drains that part of the flat nearest Alexandria. The lower part of the flat is drained by a broad, natural "swash channel," about 500 feet wide and 5 feet deep. The middle part of the flat contains, next to the river channel, a "bar" of mud, which has barely a foot of water over it at low tide. Practically the entire flat is covered with a luxurious growth of submerged plants, chiefly *Vallisneria spiralis*, or eelgrass; *Ceratophyllum* (horn wort); various *Potamogetons*, especially *Potamogeton crispus;* and a few other plants. At intervals during the year there

is a heavy growth of the green algæ, *Oedogonium*, and in later summer the tips of the larger plants support a considerable growth of *Spirogyra*. Other algæ, including *Hydrodictyon*, are present at times in considerable abundance. The variety and abundance of these plants is surprising, and needs to be seen to be appreciated. At low tide the flat looks not unlike a great meadow, level as a floor. At such times rowboats and other small craft can with difficulty penetrate the mass.

Samples were collected at four points, representing as nearly as possible the principal "biological situations" to be found here. The point designated by the letter F, near the mouth of an open sewer (R), represents "contaminated" conditions. Point G is in mid-flat, about one-third of a mile from this sewer, and about halfway to the main river channel. This was chosen to represent conditions typical of the flat, and of any other similar flats as well. The other points were selected especially for study of the gas content of water as it returned from the flat to the river channel. Point K is the lower part or mouth of Keystone Channel, which, during ebb tide, drains the up-river part of the flat. Point M, or Smiths Point, is nearly a mile farther down, but still on the riverward portion of the flat in the broad swash channel that drains the larger portion of the flat at ebb tide. Reference to map No. 9 will show the relative locations of these points.

Plankton samples were taken at points F, G, and M. Bacteriological samples and samples to ascertain CO_2 (free) and dissolved oxygen were taken at points K, F, G, and M, and samples of bottom mud for macroscopic examination at F, G, and M. No samples were taken here during the winter, as the flat was covered with ice and the sampling points were inaccessible.

Point F.—Plankton samples were collected during low tide within 200 yards of the small sewer run marked R in map No. 8. At high tide the sample was taken within 50 yards of the sewer mouth. This shifting of the point of collection was for the purpose of compensating to some extent for the large amount of dilution water into which the sewer emptied at high tide.

The water at this point is 1½ to 2 feet deep at low tide, this depth being increased by about 30 inches at high tide. The water has no appreciable odor and only a slight discoloration, which seems to be due to the sewage entering near this point, although a perceptible odor is occasionally wafted to this collecting point from the near-by sewer itself.

During summer and autumn submerged plants cover this portion of the flat. *Potamogeton crispus*, *Ceratophyllum*, and *Vallisneria spiralis*, with considerable quantities of the alga *Hydrodictyon*, are

the most abundant. Various other plants are present in small quantities from time to time.

Plankton samples collected in August show diatoms, green algæ (*Desmideæ* and a small amount of filamentous algæ), and Crustacea (Cyclops) of the cleaner water organisms. Contaminate organisms present are *Oscillatoria*, mold hyphæ, *Carchesium*, and certain rotifers. An unidentified Nematode, also an animal resembling *Euglena*, unidentified in the preserved material, are present also and persist in several other samples collected at this point.

Careful observation at several points along the open sewer showed typical conditions. Portions of the bottom were covered with tufts of *Leptomitus*. Small masses torn loose from time to time floated with the current. The water had a grayish or milky appearance at times, and bits of toilet paper, burnt matches, etc., were abundant. The edges of the stream were foul with accumulated waste, and gases bubbling from the bottom sludges produced a typical sewage odor. This stream was from 5 to 7 feet wide and shallow, under normal conditions having an average depth of about 8 inches. The rate of flow was approximately one-half foot per second.

September samples from station F tell essentially the same story. The contamination of the water by sewage is indicated by the persistence of those organisms of the plankton that are normally found in unclean water. The list in the September samples includes a few blue greens, four genera of the Rhizopoda, *Chilomonas*, of the Mastigophora (in one sample only), and *Epistylis* of the Infusoria, the latter genus in one sample only. The organism resembling Euglena appeared in all samples and the unidentified Nematode was found in one sample.

Rotifers appeared in all samples, and the presence of moderate numbers of *Cyclops*, *Chydorus*, and *Bosmina*, of the Crustacea, seemed to testify that the water was not wholly bad even at this point, though most of the samples were taken at low tide. One sample was taken at extreme high tide and contained only one pollutional organism, *Oscillatoria*.

October samples contained a trace only of *Oscillatoria* of the blue-greens, and only Conferva and *Desmidium* of the green algæ; whereas September samples had yielded 10 genera, including *Closterium* and *Cosmarium* in three samples; *Coelastrum*, *Staurastrum*, *Protococcus*, *Raphidium*, and *Tetraspora* in one sample; *Scenedesmus* in three samples; *Eudorina* in two; and *Hydrodictyon* in three. Mold hyphæ appeared in one October sample. Rhizopods and Mastigophora were not found. Infusoria were represented by a few *Codonella* in one sample, about 500 per liter. Rotifera were absent, except one doubtful specimen in one sample. The crustaceans, *Cyclops* and *Bosmina*, appeared in both samples, as did also an uniden-

tified worm, evidently a Nematode. These samples show a decided decrease in the number of organisms as compared with September samples. The presence of *Oscillatoria*, mold hyphæ, and minute worms (Nematodes) indicate a contaminated water.

No further collections for Plankton data were taken here until the following May. The broad expanse of shallow water was so stirred up by the prevailing spring winds that turbidity sometimes reached 250 and over, making it impossible to filter accurately a water sample of sufficient size to give reliable data. This condition changed rapidly, however, as soon as submerged plants got a start. The bottom mud was thus protected, and the shallow water itself steadied and held in place by the stems and leaves of innumerable plants. At first the plants can not grow rapidly, because the turbid water shuts out the sunlight; and, conversely, the water is turbid because the plants are not there to protect the bottom mud from agitation due to winds.

One sample, secured May 26, contained 22,000 standard units of *Oscillatoria* per liter, a few Rhizopods (*Arcella* and *Difflugia*), and *Rotifer actinurus* of the contaminate organisms. Various diatoms, chiefly *Navicula*, were present; also the green alga *Scenedesmus* and a few crustaceans, chiefly *Cyclops*

The Plankton content of all these samples bears testimony to the fact, already recognized, that sewage is present. In other words, the contamination of the water is reflected in the Plankton content. On the other hand, it is worthy of note that the contamination apparently is not very great even at this point, so close to the sewer. It seems that some very effective purifying agency is at work. Either the sewage is being disposed of rapidly or the apparent purification is brought about by the very large amount of well-oxygenated dilution water renewed twice daily by tidal action.

Mud samples were collected at two points, 100 feet and 300 feet, respectively, from the mouth of the sewer. The samples nearest the sewer showed, in April, a black, somewhat granular, mud, with noticeable "privy" odor. Tubificid worms were numerous, together with many egg capsules containing eggs or young. One dead snail was in this sample. Much gas arose when the mud was disturbed. Another sample taken at about the same place May 1 showed similar odor and color, but only 15 tubificid worms were found in the 200 c. c. sample.

Mud taken from the flat only 25 feet away from the mouth of the sewer showed few *Tubifex* or tubificid worms, some *Chironomus* larvæ, and contained the characteristic sewage organisms, *Paramoecium* and *Colpidium*, of the Infusoria. The sewage fungus *Sphaerotilus*, shreds of toilet paper, and the contaminate organism *Euglena viridis* were also present.

Mud samples taken 300 feet from the sewer showed a consistent increase in organisms, indicative of cleaner water. April samples were black, but had only a slightly unpleasant odor. Tubificid worms numbered only three to six per plate. *Chironomus* was present in similar numbers. Acarina ("water spider") was found in one sample. Univalve mollusks, *Planorbis parvus* and *Amnicola limosa*, appeared in two of the three samples taken in this month, totaling 14 of the first organism and 23 of the second in the two samples. One young mussel was found.

It thus appears that the evidence furnished by the inhabitants of the bottom mud is confirmatory of that already secured by examination of the plankton organisms.

Point G.—This point was in mid-flat. The water was 4 to 5 feet deep at low tide. Submerged vegetation was very plentiful during summer and autumn, persisting until November. *Vallisneria spiralis*, *Ceratophyllum*, and *Potamogetons*, with considerable algæ at times, formed the bulk of this vegetation. In late fall the dormant eel grass was densely covered with a luxurious growth of diatoms, chiefly *Cocconema*.

Plankton samples in August showed no evidence of sewage contamination, with the possible exception of the rhizopods, *Arcella* and *Difflugia*, which were present in very small numbers. Blue greens, mold hyphæ, Mastigophora, and contaminate infusoria were absent. September samples gave scant evidence of contaminate conditions. *Clathrocystis* and *Cylindrospermum* of the blue greens were present in small quantity. A few *Difflugia* (600 per liter) were found in one sample and 500 per liter of *Rotifer vulgaris* in another. In October a small amount of *Oscillatoria* was present. The diatom *Synedra* numbered about 14,000 to the liter. No rhizopods, mastigophora, or infusoria were found. November samples likewise showed no contaminate forms, with the possible exception of *Difflugia*, which appeared in one sample.

A sample taken in May, 1914, contained Infusoria that ordinarily indicate contaminate conditions. These organisms were *Tintinnus* and *Epistylis*, both present in small numbers only. It is possible that these organisms were brought from the small sewer run a third of a mile distant, or from the river channel, half a mile away, inasmuch as the submerged plants were not yet grown to such size as would check the rapid sweep of tidewater over the flat.

The evidence obtained by plankton examination of eight samples collected at this point is distinctly indicative of water of good quality.

Mud samples taken at this point in mid-flat were uniformly yellow in color, soft, and somewhat granular in consistency, and with the fresh odor characteristic of ordinary mud. In April the univalve

mollusks *Planorbis trivolvis* and *Lioplax subcarinatus* were quite abundant. A few other varieties were present, but not so numerous as the foregoing. Bivalves (*Unio*) appeared in three of the four mud samples collected in April. *Anchylus*, a univalve mollusk, was found once. The crustacean *Gammarus* was found in two samples and caddis-fly larvæ in one. Unfolding buds of *Ceratophyllum* and *Potomageton* were found in three of the April samples. No other plant life was observed. Organic remains, in the shape of snail shells in various stages of disintegration, were plentiful.

Samples in May contained the univalve mollusks, *Lioplax subcarnatus*, *Amicola limosa*, *Planorbis trivolvis* and one or two unidentified species. Bivalves (*Unio*) were present also. May-fly larvæ (*Ephemera vulgata*) were found in both samples, and in the last sample taken, May 12, were two tubificid worms. Plants present were the slowly starting submerged varieties, eel grass and Potomagetons. Organic remains consisted of a few snail shells, empty cases of caddis-fly larva, and rootlets of aquatic plants.

Point M.—A few plankton samples taken at this station during October and November, in connection with the chemical samples, gave results so similar to those obtained at point G, half a mile distant, that full details of counts would be needless repetition. One or two slight but significant points of difference are worthy of mention.

It will be remembered that this point is located in the broad swash channel, through which most of the water ebbs and flows in passing on the flat or returning from it; it is perhaps 300 yards from the main river channel. The average depth of nearly 5 feet (mean low tide) permits the passage of flood tide water quite readily over this intervening space, even in summer, as submerged vegetation is less crowded in this deeper water. It is therefore probable that water samples taken here will have been subjected to a very brief time factor in transit from the river channel. That this is a fact rather than a probability seems apparent from the presence in the plankton of certain contaminate organisms which are not found in mid-flat samples, hence they are probably brought direct from the river channel by flood tide. Furthermore, most of these organisms are found in the plankton of the river channel at Fort Foote, just below the flat.

In mid-flat samples (taken at point G) the diatom *Synedra* (regarded by many as a contaminate organism) is the most numerous diatom in four of the eight samples, whereas in the samples under consideration it is the leading diatom in five samples out of six.

In mid-flat samples contaminate organisms of the Mastigophora and Infusoria were represented by two species only, and both were

in one sample, that of May 26; whereas these swash-channel samples show one genus of Mastigophora and seven genera of Infusoria, all contaminate organisms, in addition to two forms, *Dinobryon* and *Codonella*, which are not especially typical, but seem to be indifferent to sewage contamination. The contaminate forms present are *Euglena viridis*, *Halteria*, *Colpidium*, *Enchelys*, *Epistylis*, *Stylonchia*, *Tintinnus*, and *Vorticella*. It would seem, therefore, that the proximity of this collecting point to the river channel is indicated by the presence in the plankton of those organisms which find their food supply in the bacteria attending the decomposition of organic matter, which process has not yet had sufficient time to complete its work and to banish these contaminate organisms by removing their food supply.

Mud samples taken at this station during April and May were essentially similar to those taken in mid-flat at point G, the animal life consisting largely of the univalve mollusks *Planorbis*, *Amicola*, *Goniobasis*, and *Lioplax;* the bivalve *Unio complanatus*, *Gammarus* of the crustacea; and the larvæ of May fly and caddis fly. Sponges and Bryozoa (*Fredericella*) appeared in one collection. One leech and two tubificid worms were found. Six samples were taken here during the two months. All samples were yellow or yellowish in color, with no special odor, and were granular rather than soft. Two mud samples taken in this locality, but much nearer the river channel (just on the edge of the flat), showed a few tubificid worms in both samples.

DISSOLVED GASES AND THE EFFECTS OF PLANTS.

The factors affecting the amount of free CO_2 in water are: (1) Production by bacterial activity and the presence of decomposing matter; (2) production by animal life in water; (3) absorption of CO_2 from atmosphere (to these may be added the stirring up of highly organio mud in shallow water by wind or other agency); finally, (4) absorption of CO_2 by submerged green plants; and (5) temperature.

The factors relating to dissolved oxygen in water are, in brief—(1) aeration, subsidiary considerations being depth of water and area exposed to air, agitation by wind or other agency and quality of mud thus stirred up, if in shallow water; (2) depletion of oxygen by bacterial activity or contained organic matter; (3) depletion by oxygen-using animal life in water; (4) production of oxygen by submerged green plants, this process being dependent on presence of sunlight and the absence of turbidity; (5) temperature.

Many of these factors affect the plankton organisms, either directly or through the changes produced in their environment. Bacterial

CHART J.—DISSOLVED GASES,—HUNTING CREEK FLAT,—STATION C.P.

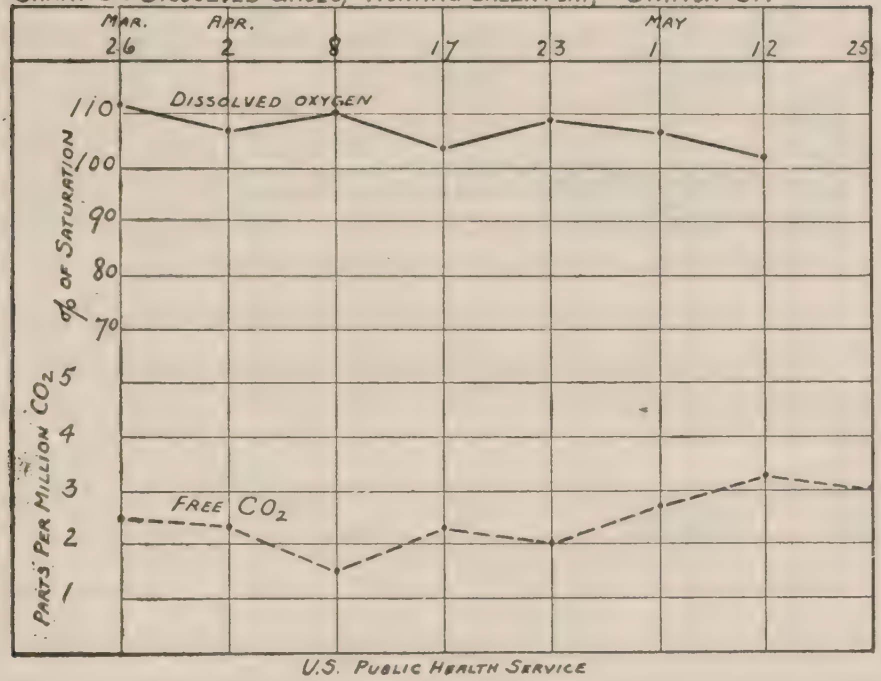

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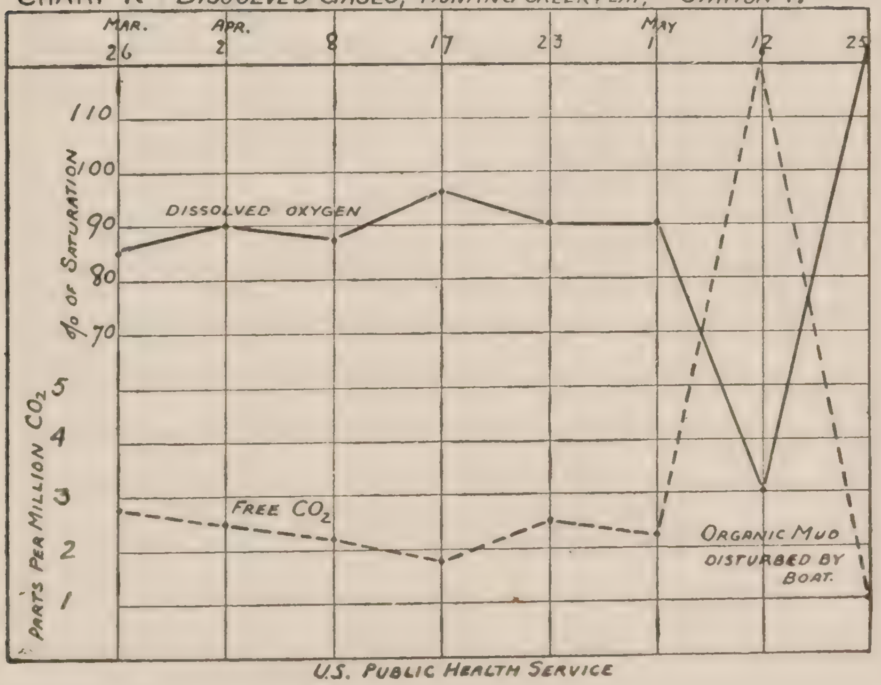
CHART K—DISSOLVED GASES,—HUNTING CREEK FLAT,—STATION F.



U.S. PUBLIC HEALTH SERVICE

CHART L.—DISSOLVED GASES,—HUNTING CREEK FLAT,—STATION G.

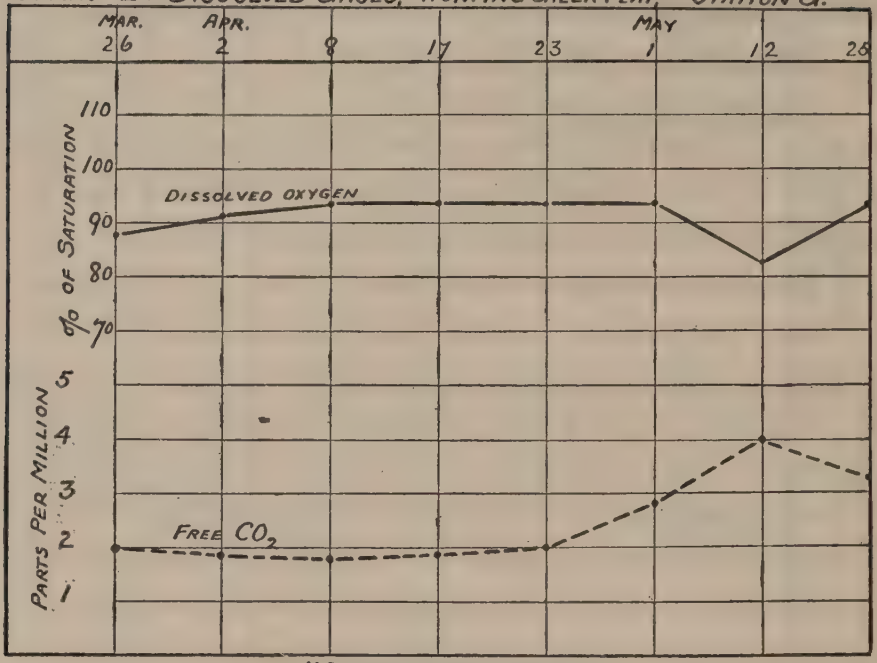


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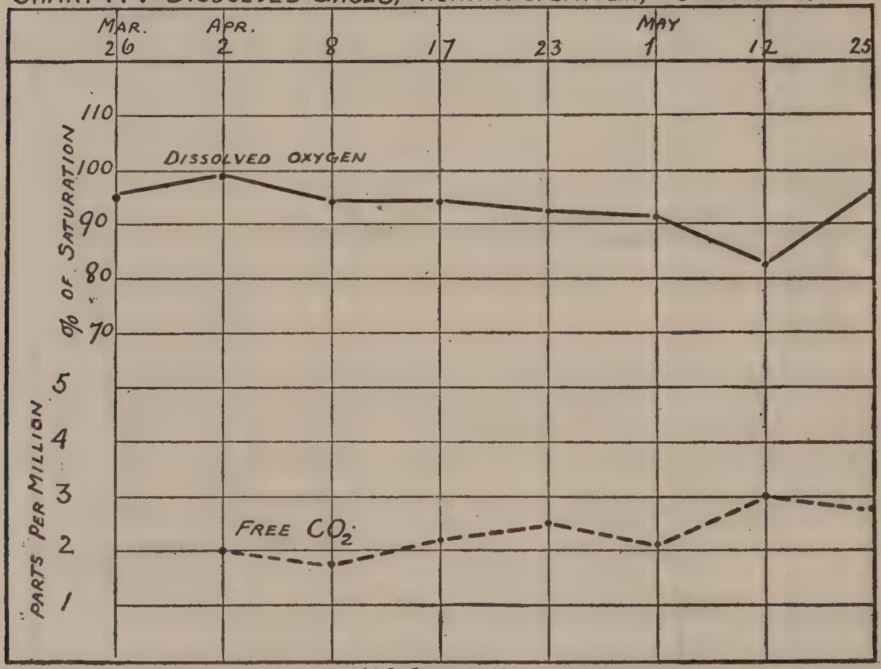
CHART M.—DISSOLVED GASES,—HUNTING CREEK FLAT,—STATION M.



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activity causes a sudden increase of those forms, chiefly Mastigophora and Ciliata[1] that feed on bacteria or on decaying matter or on both.

The "chain of food relations" thus started does not end here, but goes on indefinitely. Again, life and activity of microscopic animals will deplete the oxygen of the water and add to its CO_2 just as surely as this takes place in the aquarium containing goldfish. Further, the minute green plants, the phyto-plankton, demand CO_2 and produce oxygen by the process of photosynthesis, as the larger plants do. The presence of very large numbers of these microscopic plants compensates for their lack in size. Finally, the fluctuating amounts of CO_2 and dissolved oxygen in water may result largely from the life and activity of submerged plants, large and small, and from the action and interaction of the related factors of sunshine, turbidity, water movements, and the activity of animal planktonts, or zooplankton, as well as of larger animal life.

Relation between dissolved oxygen and plankton.—Numerous observations in the field, supplemented by laboratory examinations of water to ascertain gaseous content, indicate that intimate interrelations exist between certain of these factors of the plankton environment. A partial summary of field observations and laboratory tests is given in Tables 29 and 30. The samples for laboratory examination were taken as indicated at points F, G, M, K, and CP, the latter point being the river channel just above the flat. Reference to Map No. 8 will show the relative location of all points.

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[1] Bull. Illinois State Laboratory Nat. Hist., Vol. VIII, Art. I, pp. 63, 117, 120, 126.

TABLE 29.—*Showing the relation between various factors and amounts of dissolved oxygen present.*

Date.	Hour.	Collecting point.	Depth of sample.	Temperature (° C.).	Turbidity.	Tide.	Weather and environment.	CO_2 (p. p. m.).	Dissolved oxygen per cent of saturation.	Bacteria. 37°	Bacteria. 20°	Bacteria. B. coli (c. c.).
1914.			*Feet.*	°								
Mar. 26	11.30	CP	7	8	45	Half ebb	Diffused sunshine; breeze; waves and light swell	2.5	102	1,200	80,000	+ in 0.01
26	12.00	F	2	10	250			2.8	85.5	1,150	130,000	+ in .1
26	1.00	G	3½	10.5	130			2.0	88	650	32,000	+ in .01
26	2.00	M	4	11	110			....	94	350	30,000	+ in .1
Apr. 2	3.30	CP	8	11	55	Third ebb	Little sunshine; clouds; stiff breeze; waves and swell; water rough.	2.3	97	....	....	....
2	1.00	F	1	11	150	High flood		2.5	90	32,500	525,000	+ in .01
2	2.00	G	7	11	60	do		....	....	5,500	53,000	+ in .1
2	3.00	M	4½	11	110	High ebb		2.0	99	1,700	21,500	+ in .1
8	12.00	CP	8	13.5	45	Three-fourths ebb.	Total overcast; strong south wind; showers frequent	1.5	100	7,100	19,000	+ in .001
8	12.00	F	1	14.5	300	do		2.2	87	8,300	70,000	+ in .001
8	1.00	G	4	14	100	Low ebb		1.8	94	800	....	− in .1
8	2.00	M	5	14	60	Turn of tide.		1.7	94	2,400	14,000	+ in .001
17	12.00	CP	8	11	100	Three-fourths flood.	Sunshine; light breeze	2.3	94	23,200	220,000	+ in .1
17	2.30	F	2	14	45	High ebb		1.8	96	3,900	46,000	+ in .1
17	2.00	G	4	13	65	Flood		....	94	3,600	21,000	− in .1
17	1.00	M	4	12.5	45	High flood		2.2	94	3,300	20,000	+ in .01
23	12.00	CP	8	15	45	Two-thirds ebb.	Sunshine; calm	2.0	99.5	2,500	7,000	+ in .001
23	12.00	F	2	15.5	50	do		2.5	90	6,300	10,000	+ in .001
23	1.00	G	4½	16	60	Low		2.0	94	1,600	9,000	+ in .01
23	1.30	M	4	16	70	do		2.5	93	2,500	10,000	+ in .01
May 1	12.00	CP	8	18	110	High flood	Light overcast; diffused sunlight; light breeze; submerged plants appearing in places on flat.	2.7	97	60,000	160,000	+ in .01
1	1.00	F	1	18	100	High ebb		2.3	90	35,000	185,000	+ in .001
1	2.00	G	5	18	110	do		2.8	94	15,500	42,000	+ in .01
1	2.30	M	4	18	120	do		2.1	92	34,000	222,500	+ in .01
12	1.00	CP	7	21.5	50	One-third ebb.	Sunshine; light breeze; at F bottom sediment was stirred up by boat.	3.3	92	2,600	....	+ in .01
12	1.00	F	1	25	70	do		11.4	40	16,500	....	+ in .001
12	2.00	G	4	23	55	Low ebb		4.0	83	3,300	....	+ in .01
12	3.00	M	4	23	65	do		3.0	83	3,000	....	+ in .01
26	1.00	CP	5	24	30	Two-thirds ebb.	Sunshine; light breeze; submerged plants growing in many places; large amount of Potamogeton crispus at F.	3.0	....	....	....	....
26	4.00	F	1½	28	35	Low flood		1.0	125	....	....	....
26	3.00	G	3	25	35	Turn of tide.		3.3	93	....	....	....
26	3.00	M	3+	25	35	Low flood		2.8	96	....	....	....

TABLE 30.—*Showing the relation between various factors and dissolved oxygen.*

Date.	Hour.	Collecting point.	Depth of sample.	Temperature (°C.).	Turbidity.	Tide.	Weather and environment.	CO_2 (p. p. m.).	Dissolved oxygen, per cent of saturation.
1913.			*Feet.*	°					
Oct. 15	11.30	K	9	17	28	Half ebb	Partial overcast; diffused sunshine; much eelgrass and algæ present		65
15	11.30	K	4	17	28	do			66
15	10.00	M	3½	16	20	Ebb			73
15	11.00	J				do			−62
22	4.00	K	4	13.5	16	do	Sunshine; light breeze; eelgrass and algæ abundant		83
22	5.00	M	4	13	12	do			111
22	5.00	M	2½	13	12	do			72
22	11.00	J				High			−79.5
29	11.00	K	8	14.5	180	Ebb	Sunshine; hazy clouds; water very muddy in river channel (250 turbidity); submerged plants partly obscured by turbidity		89
29	10.00	M	4	14.5	15	do			89
29	10.00	M	3	14	35	do			85
29	11.00	J			250	do			60.7
Nov. 5	4.30	K	7	11	30	do	Sunshine; nearly calm; eelgrass, tipped with bunches of *Spirogyra*	2.9	89
5	3.00	M	4	11	24	do			104
5	3.00	M	4	10	24	do		1.4	101
5	11.00	J							85.6
12	11.00	K	7	7	250	do	Sunshine and hazy clouds; eelgrass and *Spirogyra* abundant	2.0	96
12	10.00	M	3+	6	70	do		2.0	89
12	10.00	M	4+	6	28	do		2.5	92
12	11.00	J				do			101.
19	5.00	K	7	9	50	do	Slight overcast; calm; mud-laden eelgrass; algæ on tip	2.5	91+
19	4.00	M	4	8.5	35	do		2.5	87
19	11.00	J				High			100
26	11+	K	8	8.5	45	Ebb	Raining; eelgrass still retains place on flat	2.0	81
26	10.00	M	4	9	40	do		1.3	84
26	11.00	J				do			84.5

In aquatic plants and animals, including microscopic forms, there is a sort of reversal of the relative conditions required by land organisms. The latter grow in air, their natural medium, and require much or little water, but they must have water. The aquatic organisms grow in water, their natural medium, but they must have certain amounts of the gases to be found in air. Submerged green plants, like land plants, utilize inorganic food material, chiefly CO_2 and water, in the manufacture of their food and give off an excess of oxygen as a waste product, this activity depending largely on the access of sunlight to the chlorophyll within the plant cells. This process, photosynthesis, produces both chemical and biological effects, the former being the addition of oxygen to the surrounding water and the extraction of CO_2 from it, and the latter, or biological, effect being the increased activity of oxygen-using bacteria, and of animal life, microscopic and larger, made possible by the renewed supply of oxygen to the water. These animal forms, in turn, produce CO_2, which may be utilized by the green plants. To a certain extent the respective activities of the aquatic plants and animals are reciprocal.

The plants thus become a factor of considerable importance in the economy of the river. In addition to the enforced sedimentation and clearing of the water and the prolonged period for biological action in the sewage-laden water brought in by the flood tide, there is the equally important reoxygenation of the water by these plants meantime, thus furnishing to the aerobic bacteria and microscopic animals the means of continuing their activity in the so-called self-purification of the river. In support of this statement there is appended the following condensed tabulation showing the average dissolved oxygen content of 27 samples taken from the flats and of 12 samples taken from the adjacent river channel on the same days:

TABLE 31.—*Dissolved oxygen on flats and in channel.*

Sampling point.	Number of samples.	Dissolved oxygen content, percentage of saturation.		
		Highest.	Lowest.	Average.
Flats	27	128	57	87
River channel	12	102	50	71

The samples were taken September 3 to November 12, inclusive. Plants were much reduced in numbers and activity in November. Eelgrass, though inactive, was still present, and was covered with a mass of diatoms (chiefly *Cocconema*) and tufts of *Spirogyra*. Both the algæ and the diatoms contained the synthetic work of the defunct eelgrass.

If the data in the preceding table be arranged with reference to tidal conditions when samples were taken, we have the following:

TABLE 32.—*Dissolved oxygen at high tide and at low tide.*

Sampling point.	Number of samples.	High or rising tide—dissolved oxygen (percentage of saturation).			Number of samples.	Low or falling tide—dissolved oxygen (percentage of saturation).		
		Highest.	Lowest.	Average.		Highest.	Lowest.	Average.
Flats	8	128	57	83	19	127	62	88
River channel	8	86	60	67	4	102	50	76

These results indicate that the rising tide floods the flats with water which is lower in dissolved oxygen than the water already on the flat, and that the ebb tide carries to the river channel a volume of water relatively higher in dissolved oxygen than the channel water itself. This matter will be discussed quantitatively in a later section.

Sunlight and turbidity.—Oxygen production by green plants depends on sunlight, and this, in turn, may be greatly reduced by clouded skies, or entirely shut off from submerged plants by turbidity of the water.

If the dissolved oxygen data from the flats be arranged with reference to sunny and cloudy days when samples were collected we have:

TABLE 33.—*Sample collected from flats on sunny and cloudy days.*

Sky.	Number of samples.	Dissolved oxygen (percentage of saturation).		
		Highest.	Lowest.	Average.
Sunny	16	128	72	99
Cloudy overcast	11	87	57	69

If from the above sunny days we exclude five, on which the water had a turbidity of 30 or over (sufficient to exclude most of the sunlight), and place these readings with those of the cloudy days, we have an average of 103 per cent dissolved oxygen for the sunny days and 75 per cent for the cloudy.

If it be true that water on the flats is higher in dissolved oxygen because of plant activity during sunny days, then it follows that water in the river channel also should exhibit increase of dissolved oxygen during these days, because of the oxygenated water received from the flats during ebb tide. This is shown in a measure by Table 34, following. (In this table the first week in September is omitted because of absence of data concerning local weather conditions.)

TABLE 34.—*Dissolved oxygen (percentage of saturation) on cloudy and sunny days.*

	Three Sisters.		Below railroad bridge.		Giesboro Point.		Fort Foote.	
	Cloudy.	Sunny.	Cloudy.	Sunny.	Cloudy.	Sunny.	Cloudy.	Sunny.
1913.								
Sept. 8		90.6		60.5		39.2		46.2
Sept. 9		92.6		80.1		59.3		47.4
Sept. 10		87.2		76.7		48.5		52.5
Sept. 11		91.2		85.1		63.9		50.1
Sept. 12		94.2		79.1		66.9		46.8
Sept. 13		93.4		71.8		64.6		42.2
Sept. 15		95.7		73.1		66.4		56.9
Sept. 16								66.4
Sept. 17	96.4		76.3		64.0		60.0	
Sept. 18	97.5		75.3		57.1		59.0	
Sept. 19	100.8		68.9		53.3		58.5	
Sept. 20	90.1		56.9		40.4		58.8	
Sept. 22								
Sept. 23		96.8		83.9		68.4		58.4
Sept. 24		96.2		80.1		66.8		59.6
Sept. 25		94.9		79.4		68.1		53.2
Sept. 26		91.6		82.9		70.4		57.3
Sept. 27				87.9		78.6		68.5
Sept. 29		99.6		89.9		74.9		60.7
Sept. 30		99.0		88.6		69.4		56.5
Average	96.0	94.0	69.0	80.0	54.0	65.0	59.0	55.0

It will be noted that there is no essential difference in favor of sunny days in samples taken at Three Sisters. This, however, is entirely consistent, because this collecting point is in the narrow, upper river, before the water has had access to plant-filled flats. Plants are not a factor in this part of the river, hence sunny days produce no excess of oxygen in the water. At the other collecting points named, the water has had access to flats containing large amounts of submerged plants. As a result, the sunny-day samples show a distinct increase in dissolved oxygen.

At Fort Foote the results as shown seem to be inconsistent. However, it is possible that the process of decomposition, inaugurated by the recent addition, only 4½ miles above, of the sewage of Washington, are so vigorous at times as to mask the addition of oxygen from the flats. Turbidity records for the channel are lacking, but such turbidity would be no essential factor in this instance, because the water whose dissolved oxygen content is concerned is that contributed from the flats to the channel. There are no plants of importance in the channel, neither is there turbidity on the flats at this season. The dissolved oxygen data from Fort Foote for the succeeding month of October show an average of 61 per cent of saturation for samples taken on cloudy days and an average of 78 per cent of saturation for sunny-day samples. In this month the cloudy and sunny days are more evenly distributed, there being 14 of the one and 13 of the other, and it would seem that the average readings, as given, would therefore be significant.

A summary of the data from Fort Foote during September, October, and November (to the 15th) gives the dissolved oxygen readings for sunny and cloudy days arranged, in Table 35, with reference to tides:

TABLE 35.—*Dissolved oxygen averages at Fort Foote with reference to tides and sunshine.*

Month.	Samples collected during low tide.		Samples collected during high tide.		Average dissolved oxygen (percentage of saturation)—	
	Cloudy.	Sunny.	Cloudy.	Sunny.	At low tide.	At high tide.
1913.						
September	6	3			61	
Do			0	9		25
October	9	7			70	
Do			8	2		67
November (to Nov. 15)	4	4			93	
Do			2	3		83

These samples were collected about the same hour (11 o'clock) each day, hence the ebb-tide water had been exposed to only a part of the plant activity for that day. It is probable that samples taken in the late afternoon would have shown a much higher percentage of dissolved oxygen. That this is so is indicated by Table 36, here given.

TABLE 36.—*Dissolved oxygen content of water ebbing from Hunting Creek Flat, forenoon and afternoon samples.*

Collecting point.	Symbol.	Number of samples.		Average dissolved oxygen (percentage of saturation.)
		A. M.	P. M.	
Smiths Point	M	6		85
Do	M		5	95
Keystone Channel	K	5		79
Do	K		3	88

These samples were taken from Hunting Creek Flat, just above Fort Foote, during October and early November, while plant life (submerged) was still somewhat active. The collecting points were carefully chosen so samples would faithfully represent the average water ebbing from the flat. All samples were taken during strong ebb tide, and at a depth equal to about three-fourths the total depth of the water at the collecting points, the locations of which, designated by M and K, respectively, are shown in Map No. 9.

Aerating capacity of tidal flats.—The results of Tables 35 and 36 can now be utilized in a quantitative computation of the aerating capacity of these tidal flats. Having in mind the important fact that

the capacity of any stream to receive and oxidize sewage, without depleting its available oxygen to the nuisance point, is determined primarily by its capacity for reaeration, a quantitative estimation of the reaerating effect of tidal flats covered with vegetation is a matter of some importance.

The character of water going to the flats from the river is indicated by the average condition at high and low tides at Fort Foote, immediately below these flats. This condition is shown in Table 35, taking the average of all October and November figures to be 75 per cent of saturation. Assuming that approximately twice as much water leaves the flats by the Smith Point Channel as by the Keystone Channel, an assumption which is reasonably accurate, the average character of that water is found from the data of Table 44 to be 83 per cent saturated following a night flood tide, and 93 per cent saturated following a day flood. The increase is therefore 8 per cent of saturation for night tides and 18 per cent of saturation for day tides, a total of 26 per cent of saturation for the entire tidal prism during each 24 hours. At the average temperature obtaining during the months of October and November the saturation point of oxygen in water is approximately 10 parts per million. The tidal range over the same period was approximately 30 inches.

Computing the results per acre of tidal flats, it is found that the production of oxygen amounts to about 17.7 pounds per acre per day. The Washington sewage during this same period had an oxygen demand, as will be shown later, of approximately 300 parts per million; that is, 1,000,000 gallons of sewage requires for its ultimate oxidation biologically, 2,500 pounds of oxygen. One hundred and forty-one acres of tidal flats, under the conditions obtaining in September and October, therefore produced sufficient oxygen for the complete biological oxidation of 1,000,000 gallons of sewage.

The true effect of this aerating system is very largely masked by one important fact—namely, that these flats are themselves extensively polluted by the sewage of Alexandria, and the tidal flow upon them is also polluted by the sewage of Washington. The actual oxygen production of the flats must therefore be greater than the figures calculated above by the total oxygen demand of the Alexandria sewage which passes through this region, and the 12-hour oxygen demand of that fraction of the Washington sewage which ebbs and flows over these flats.

Effects of temperature.—It is important also to note the temperature relations. Biological activities were very much less during the time of these observations than during the warmer summer months, and it is probable that during the summer season, which is coincident with the period of greatest danger from physical nuisance, the aerating capacity of these flats is much greater than the figures

indicate. On the other hand, during the winter months, this aerating capacity is of little, if any, significance. It will be of interest to record for comparison that these flats, under the conditions noted, furnish a means for the complete oxidation of sewage at a rate in excess of 7,100 gallons per acre per day, while artificial sand filtration of sewage is carried on at rates from 10,000 to 100,000 gallons per acre per day. With an area of 1.3 square miles Hunting Creek Flat is apparently able to complete the oxidation of all the Alexandria sewage which enters it and also to provide for the complete oxidation of nearly 6,000,000 gallons per day of the sewage from Washington. If, instead of the total, the 24 hours' oxygen demand be used in this computation, this result is increased approximately fivefold. In other words, this flat will provide sufficient oxygen for the first 24 hours' natural purification of nearly 30,000,000 gallons of Washington sewage. As it is this first 24 hours' demand which constitutes the critical point in stream pollution, this figure is of more definite significance and doubtless explains in large measure the relatively slight effect of the Washington sewage in decreasing the oxygen of the Potomac River at points below.

That this oxygenation is in the main biologic rather than physical, due to mere exposure upon the flats, is indicated in Tables 29 and 30. The average condition of the flood waters in the river was 67 per cent of saturation, of the waters over the flats during the cloudy days of the same period, 69 per cent. The average condition being exposure of the flat waters for half a tide, it may be assumed that the change for a whole tide would be twice as great, indicating an increase of 4 per cent of saturation. This value is lower than that of the night floods of Table 34, which show an increase of 8 per cent of saturation; but these tides, being in reality forenoon ebbs, had certain hours of daylight. Upon cloudy days, however, with the photographic intensity of actinic rays ranging from 3 per cent to 10 per cent of full sunshine, following eight hours of darkness, the biologic oxygenation is reduced to its lowest term. Purely physical re-aeration, therefore, is certainly not over 33 per cent of the total effect, and if proper allowance could be made for the residual biologic action upon cloudy days, perhaps 6 per cent of full sunshine, this figure would be materially reduced.

TIDAL ACTION ON THE FLATS.

The tides in the Potomac River constitute an automatic device whereby nature lifts vast quantities of contaminated river water and spreads it over the large area of the flats, which in summer are equipped with effective bafflers and oxygenating apparatus—the plants. For six hours the water is slowly pushed into these renovating delay stations; then, for an equal period, the mixed water is

slowly drawn back into the channel, possibly to repeat the process farther down the river. Unlike man's purifying devices, this apparatus works day and night, without attention and without expense. Furthermore, the machinery of this water purification plant is absolutely "fool proof."

Movements of tidewater on the flats are strikingly similar to the movements of air in the lungs. Ordinary tides correspond to ordinary breathing—a very high tide is analogous to a deep inhalation of air and a very low tide is similar to an enforced exhalation. Finally, the "residual air" in the lungs typifies the large body of "residual" water which remains on the flats, continually renewed, constantly depleted, yet never exhausted.

By checking the normal current the flood tide virtually makes a vast sedimentation basin of a large part of the river, and greatly increases the time required by the water to reach a given point downstream. Time rather than distance is of utmost importance to permit the breeding of those organisms, both bacteria and plankton, whose activity results in the destruction of organic matter. This time factor, together with resulting improvement of the water, is further increased by the spreading out of water on the flats. It seems reasonable to suppose that this water, pushing its way slowly through the submerged plants and mixing thoroughly with the residual water, must be subjected to prolonged sedimentation, aeration, and general readjustment of chemical and biological conditions.

The amount of the improved water returning to the channel at ebb tide is considerable. An estimate of the daily contribution of Hunting Creek Flat, with an area of 1.3 square miles and an average tide of 30 inches, shows that this flat alone pours into the channel about 167,720,000 cubic feet in 24 hours, and that the combined contributions of the 10 square miles of flats between Washington and Marshall Hall will be approximately equivalent in 24 hours to a tributary whose discharge is 14,520 cubic feet per second. This is about equivalent to the Alleghany River at Kittanning, Pa., at half-flood stage; or to the Muskingum, at Zanesville, Ohio, at medium-flood stage; or to the Ohio River at Wheeling, W. Va., at low-water stage; or to the Wabash, at Terre Haute, Ind., at medium flood. Thus a large part of the water is subjected on the flats to a long period of general improvement through biological, chemical, and physical factors brought into action by this temporary impounding of the water by the tides, in these delay stations of the Potomac.

DECAY OF SUBMERGED PLANTS.

In late fall the submerged plants disappear slowly. Weakened by decay, many of them are broken from their attachments in the bottom mud and are carried out to the channel by the ebb tide. As

the plants are thus thinned out, tides increase in force on the flat, because of the gradual removal of these plant barriers. Finally, the ice, floating out in the spring, removes much of the débris that may have resisted the force of the tidal water.

It seems reasonable that the decay of this large amount of organic matter should have some injurious effect on the water, but accurate data are lacking. However, as far as we can judge from the amounts of dissolved oxygen and free CO_2 in the water, it seems that there is no special bacterial activity in November, for instance, when most of the plants have completed their work and are being swept out by the tide. During this month, or from November 5 to 26, ten samples of water (see Table 30), taken at points K and M (see Map No. 9), during strong ebb tide, showed on an average a dissolved oxygen content of 91 per cent of saturation and an average CO_2 content of 2.1 parts per million. These results do not indicate any particular activity as to bacterial decay.

During this same period of time, however, the average dissolved oxygen in the adjacent river channel at Fort Foote was 93 per cent of saturation. This small increase over the amount found in ebb-tide water from the flat might be interpreted as an indication of a slight increase in bacterial activity on the flat.

During the period from March 26 to May 26, 1914, 22 samples from Hunting Creek Flat (see Table 29) gave an average of 2.4 parts per million CO_2 and 93 per cent saturation of dissolved oxygen. (This does not include sample taken at F May 12, when organic mud, stirred up by the boat, gave to the water high CO_2 and low dissolved oxygen content). During the same period, eight samples collected from the river channel at CP (just above the flat) showed an average of 2.5 parts per million of CO_2 and 97 per cent saturation of dissolved oxygen. Thus the relative conditions of channel water and flat water were about the same as in November, though decaying plants were absent.

It is possible that the decay of the plants takes place so gradually that their retreat is covered by the excess of oxygen provided by the plants which remain for the time being. Submerged plants are protected from the extremes and sudden changes of temperature which assail land plants and check their activity. Autumn frosts do not menace the aquatic forest. Some of these submerged plants continue their activity far into November, and one or two varieties occurring in small quantities seemed to the writer to be as green and active as ever on November 26.

The products of decay of these larger plants are apparently utilized by certain microscopic algæ, such as *Scenedesmus* and *Raphidium*. The minute alga *Coleochaete* grows luxuriantly on a fragment of decaying water plant, as moss grows on a rotting log. An

experiment by the writer demonstrated that water plants, decaying in a jar of water, may be accompanied by microscopic algæ in such numbers that a distinct oxygen reaction is produced when a fragment of the decaying plant is placed in fresh hemotoxylin solution. In this instance the microscopic plant was a plankton organism (*Scenedesmus*) which is very common in Potomac water.

In the late fall the tips of eelgrass (which, though apparently dormant, retains its hold on the bottom mud until late in November) are seemingly covered with mud for a distance of 1 to 2 feet of the blade. On inspection this covering is found to consist chiefly of diatoms, principally *Cocconema*, whose brown color gives the appearance of mud. On placing a piece of this diatom-covered eelgrass in the hematoxylin solution, and exposing to a bright sunlight, a distinct and vigorous oxygen reaction resulted in less than half an hour.

It thus seems probable that the presence of innumerable microscopic plankton organisms such as *Scenedesmus* and diatoms may by their synthetic action produce quantities of oxygen sufficient to counterbalance the products of decay in the larger plants, and may thus maintain a safe oxygen content in the water. This is a most interesting possibility, and one that should be carefully investigated.

TURBIDITY.

The turbidity of Potomac water is due (1) to excessive rainfall and general flood conditions in the upper Potomac and tributary streams; (2) to the stirring up of mud on the shallow flats during winter and spring, when the protective covering of plants is absent. In the spring floating ice stirs up the mud on the shallow margins of the river, and especially when the ice finally floats away from the shallow flats the broken masses stir up the mud, causing high turbidity in the nearby channel. During late fall and early spring, when neither ice nor plants are on the flat, the shallow water is agitated by the wind, the mud is stirred up, and the tide ebbing from the flat carries a flood of muddy water to the channel.

On October 8 the water in the river channel showed a turbidity of 140, while the water 200 to 300 feet away in the flat showed a turbidity of only 13 and 19, respectively. This was due largely to the presence of the plants, which compelled the water from the channel to seep through very slowly to the flat. Conditions similar to this were observed many times. Of 65 turbidity readings taken in the channel and 42 taken on the flats during August, September, October, and November, 25 of the channel readings were less than 20; 19 were 20 or more, but less than 40; 15 were over 40, but less than 100; and 6 were 100 or over; the average was 38. Of the turbidities taken on the flats, 24 were less than 10; 10 were 10 or over, but less than 20; while only 8 showed turbidity of 20 or over. The average was 14, which means water that is very clear.

On the other hand, on March 26, during a stiff breeze that produced "white caps," the channel water showed a turbidity of only 45, while the water on different parts of the adjacent flat showed turbidities of 100, 110, 130, and even 250, the latter being in the shallowest part of the flat, where the soft mud was continually stirred up by wind-produced waves. Again, on April 28, while the channel turbidity was 45, less than 50 feet away from the channel on the flat the turbidity was 100 and on the shallowest part of the flat the turbidity was 300.

Twenty-six turbidity readings were taken on the flats during March, April, and May, and the same number was taken in the river channel above the flat during the same months. A comparison of these is significant. The shallow flats were not yet protected by the summer growth of submerged plants. Of the channel readings, 9 were less than 40, 14 were between 40 and 100, and 3 were over 100; the average of the 26 readings was 52.5. Readings taken on the flats showed 3 less than 40; 12 were between 40 and 100; 9 were over 100, but less than 200; and 2 were over 200; the average of the 26 readings on the flats was 94+. All the above readings were taken above that portion of the river where the mingling of salt water with the fresh precipitates the suspended matter and tends to produce clear water. All readings were taken with the United States Geological Survey turbidity rod.

DISPOSAL OF SEWAGE ON FLATS.

Inspection of data in Table 29 (exclusive of May 26, when plants were active) will show, concerning points F. G. and M—

1. That dissolved oxygen is lowest at F in every case but one, that being at high tide April 17.

2. That CO_2 is highest at F except in two instances, both at high tide, one instance being the above date.

3. That bacterial counts are highest at F.

4. That in four samples out of 7 water at F is *B. coli* positive in 0.001 cc., samples from other points being distinctly better.

5. That dissolved oxygen values fluctuate but little (omitting, for obvious reasons, the sample taken at F on May 12).

Data in Table 30 show:

1. That ebb-tide water from the flat taken at Keystone Channel is lower in dissolved oxygen and higher in CO_2 than samples taken simultaneously at M.

2. That the average dissolved oxygen of ebb-tide water from Keystone Channel is about the same as that of samples taken from the river channel at Fort Foote on the same days.

3. That dissolved oxygen values fluctuate widely.

A sewer of moderate size empties near F. (See Map No. 8.) Most of the water from this portion of the flat is conducted to the river channel, three-fourths of a mile away, by Keystone Channel. It is evident that water at F is affected by sewage. Also, samples collected from Keystone Channel at point K still show to a small extent the effects of this contamination, the average gas content here being 2.3 parts per million of CO_2 and 83 per cent saturation of dissolved oxygen, while samples taken simultaneously at M where water from mid-flat passes into the river channel averaged 90 per cent saturation of dissolved oxygen and 1.9 parts per million CO_2. The average dissolved oxygen in the adjacent river channel was 82 per cent of saturation.

The scattered data available are scarcely sufficient to establish anything of value concerning the fate of the sewage. It is significant, however, that the water, so far as examined, maintains a uniformly high degree of excellence as to oxygen content, thus strengthening the evidence furnished by the plankton. By the time the water reaches the river channel the sewage, as such, has practically disappeared. Whether this disposal has been effected chiefly by dilution, by activity of bacteria and plankton, by submerged plant life and consequent increase in dissolved oxygen, or by aeration and sedimentation, or by all of these factors in combination, is an unsettled question.

When the last samples were collected, May 26, submerged plants (chiefly *Potamogeton crispus*) were quite abundant near F, but were relatively few in other parts of the flat. At this time dissolved oxygen at F was 125 per cent of saturation and CO_2 was one part per million. Unfortunately no further collections were available by which these findings might be confirmed.

It is possible that the advent of plant activity provides for the retention and ultimate disposal of sewage entering the flat at this season. There is very rapid development of these submerged plants about the last of May and the first part of June, when they finally overcome the turbidity of the water and gain access to the sunlight. It may be that at such a time food material is at a premium and that the needy plants seize upon any organic material dissolved in the water. Further investigations should throw light on this matter.

POTOMAC ESTUARY.

This includes the lower portion of the so-called river, extending from the region of Maryland Point, 42 miles below Washington, to Chesapeake Bay, a stretch of 60 miles. This body of water, one and three-fourths miles wide at Maryland Point, rapidly widens until, at Colonial Beach, 20 miles below, it is nearly 5 miles in width, this dimension remaining approximately the same to the mouth. The water is brackish, becoming salt toward the lower end. The charac-

teristics of a bay, rather than those of a river, prevail. For convenient reference, Table 37 gives collecting stations, together with distances from Washington and from Point Lookout. Relatively few samples were taken in the lower river. Organisms indicating pollution were so rarely present that it seemed advisable to confine the investigations largely to that portion of river that showed evidence of pollution and of its gradual disappearance.

TABLE 37.—*Stations on lower river—Distances from Washington and from Chesapeake Bay.*

Stations.	Miles from Washington.	Miles from Chesapeake Bay.	Stations.	Miles from Washington.	Miles from Chesapeake Bay.
Possum Point	24	78	Bretons Bay	78	24
Liverpool Point	32	70	Ragged Point	84	18
Maryland Point	42	60	Piney Point	89	13
Popes Creek	53	49	Sandy Point	91	11
Lower Cedar Point	57	45	St. Georges Island	93	9
Colonial Beach	64	38	St. Marys River	95	7
Blakistone Island	76	26	Cornfield Point	100	2
St. Clements Bay	76	26	Point Lookout	102	0
Nomini Bay	77	25			

TABLE 38.—*Potomac River investigation—Biological samples, lower river, Possum Point to Chesapeake Bay.*

Region included.	District.	Number of samples.				
		Plankton.	Mud.	Submerged plants.	Aquatic animals.	Total.
Possum Point to Colonial Beach (including Liverpool Point, Maryland Point, Popes Creek, and Lower Cedar Point)	I	15	17	5	3	40
Blakistone Island district (including St. Clements Bay, Nomini Bay, and Bretons Bay)	II	7	3	3	4	17
Ragged Point to St. Marys River (including Piney Point, Sandy Point, and St. Georges Island)	III	8	4	4	8	24
Point Lookout (including Cornfield Point, Coan River, and Hog Island)	IV	4	5	3	6	18
Total		34	29	15	21	99

DISTRICT I.

The various collecting points have for convenience been grouped as shown in Table 38. District I represents a stretch of about 40 miles, in which the fresh water gradually becomes brackish and much of the mud is precipitated. The water is usually clear at Colonial Beach in consequence. No polluting material worthy of note is added to the water in this stretch. No tributaries of importance enter the river between the points mentioned in the table, but there are eight expansions or flats of considerable size and a few smaller ones, all of which probably serve as delay stations. The river itself is from one to three miles wide.

Plankton.—Fifteen plankton samples were taken in District I, six during December, 1913, and nine in May, 1914. December samples showed 12 genera of diatoms; May samples, 8 genera. *Synedra* was the most numerous in only 1 sample, but it was present in 5 samples. Other leading genera were *Navicula* in 6 samples, and *Stephanodiscus* in 9. Blue greens were not found. *Scenedesmus*, of the green algæ, appeared in one sample only, and a small amount of *Conferva* in 2 samples. Mastigophora were represented by *Peridinium* and *Glenodinium*, flagellates which were not found at all in the numerous collections from *Three Sisters* to *Marshall Hall*. *Glenodinium* was found in small numbers in three collections, all from the river channel near Popes Creek, about 50 miles above Chesapeake Bay. Peridinium was present in one of these samples in considerable abundance—32,000 per liter of water. This organism was not found in any other sample in this 40-mile stretch of river.

Infusoria were present in every sample. *Codonella* predominated, appearing in moderate numbers in most of the samples. Another variety of *Codonella*, with posterior part of lorica pointed instead of rounded, appeared in four or five samples. This organism was not found in the plankton of the upper portion of the river. This is true also of another Infusorian found in five of these samples in moderate abundance—1,500 to 4,000 per liter. This organism evidently belongs to the genus *Tintinnus;* the lorica is cylindrical and is constricted near one end, producing a shape similar to that of a long bottle. The rotifer *Anuraea cochlearis* appeared sparingly in two samples. Crustacea were more abundant. *Cyclops* were present in nine samples and the large form, *Acartia*, was found twice. These forms were present in moderate numbers only, reaching 2,000 per liter in one sample.

Bottom samples.—Mud samples, to the total number of 16, were taken from Possum Point, Maryland Point, Popes Creek (river channel), Smiths Point, Lower Cedar, and Colonial Beach. The bottom mud is abundant, very soft, and both granular and sticky. Usually it is yellow on the surface and dark or black beneath. Some samples gave forth no odor, but the majority had an odor indicating somewhat stagnant conditions. Samples from Possum Point contained a very few tubificid worms, four in one sample, two in another, and one *Chironomus* larva appeared in a third sample. One young bivalve mollusk was found. Five samples taken at Maryland Point, 18 miles farther down, yielded two young mussels, the crustacean *Gammarus* in one sample, mud tube of Nereis (a marine sandworm) in one sample, a specimen of the worm itself (young) in another, and one tubificid worm.

Mud from the river channel at Popes Creek, 29 miles below Possum Point, showed one or two tubificid worms in each sample. *Gammarus*

appeared in two samples in moderate numbers. The marine crustacean *Squilla*, and the marine worm *Nereis* were found, one each and both young, in one sample. Mud from Lower Cedar Point contained a few young mussels, one *Gammarus*, and two tubificid worms. Two or three other samples taken in the lower portion of this stretch of river contained *Gammarus*, *Squilla*, and mud tube of *Nereis*. No living plants were found except a few bits of blue-green alga in one sample from the channel at Popes Creek.

DISTRICT II.

This district, 12 miles below Colonial Beach, includes only about 2 miles of the river's length. Wicomico River, in reality a bay of considerable size, and Bretons Bay, Nomini Bay, and St. Clements Bay increase the river's area and their drainage basins contribute a small amount of fresh water. Much fishing is done in this part of the river and the oyster industry is important. No source of contamination is apparent.

Plankton.—Samples were taken in the river channel near Blackistone Island, December 17, 1913, January 13, and May 19, 1914. The winter samples showed seven genera of diatoms in one collection and the summer samples contained four genera. The most numerous in winter samples were *Stephanodiscus* (6,500 per liter) and *Asterionella* (9,000). *Pyxilla* was found here, the first time this curious diatom has appeared in the plankton thus far. *Fragilaria*, *Navicula*, *Cyclotella*, and *Synedra* appeared in small numbers. *Melosira* (8,000 standard units) was found in the summer sample.

Blue-green algæ were not found. Green algæ occurred sparingly in two samples. Neither Fungi nor Rhizopods were found. Mastigophora, or rather Dinoflagellates, were present in abundance in all collections; those in winter showing *Peridinium* (90,000 per liter), *Ceratium* (4,500), and a very few *Glenodinium*, while the summer collections showed about 4,000 of the latter per liter.

Infusoria were represented in all samples by *Codonella* in small numbers. In the May sample, *Tintinnus* was found, 5,000 per liter. The rotifers *Colurus* and *Synchaeta* were present in small numbers in the winter samples. *Cyclops* and *Acartia* of the crustaceans occurred in moderate numbers in all channel samples.

Samples taken in St. Clements Bay and in Bretons Bay yielded a plankton content essentially similar to that from the river channel. They differed chiefly in the fact that the Dinoflagellates were less abundant and the crustacea, especially *Acartia*, were more abundant, there being as many as 14,000 of the latter per liter in the sample from Bretons Bay.

No organisms indicating contaminate conditions occur in the foregoing list, with the possible exception of a few *Tintinnidae* in one sample. Positive evidence of contamination is lacking.

Bottom samples.—Mud samples gave little evidence of a definite character. One sample contained *Nereis*, the marine "sandworm." No plant life was found. Fragments of oyster shells were moderately abundant. The mud was soft and sticky, yellowish and gray in color, with a trace of "stale" odor.

DISTRICT III.

Plankton.—This stretch of 11 miles extends to within 7 miles of the river's mouth. A branch estuary (St. Marys River) penetrates the Maryland shore for a distance of 9 miles. This body of water, over a mile wide at the mouth, provides another commodious delay station for the lower Potomac.

Three plankton samples were taken in December, 1913—three in January and one in May, 1914. The depth of the Potomac here varies from 20 feet near the shore to a maximum of about 80 feet in some parts of mid-channel. December samples taken in the edge of the channel at Ragged Point (8 miles below District II) showed 13 genera of diatoms. The most aboundant was the curious filamentous form *Chaetoceros*, of which there were about 13,000 standard units per liter; *Pleurosigma* (3,000 per liter), *Stephanodiscus* (2,600), *Asterionella* (2,500), *Navicula* (1,900), and *Cyclotella* (1,800) were the other leading genera. *Pyxilla* and *Synedra* were present in small numbers.

A small bit of blue green was found in one sample, also samples of two green algæ, one of which was evidently *Ulothrix*. *Crenothrix* appeared in one sample in small amount, *Difflugia pyriformus* (400 to the liter) was found. Of the Mastigophora the Dinoflagellate *Creatium* appeared, 1,500 to the liter. *Codonella*, of the infusoria, was present to the number of 2,700. No rotifers nor crustaceans were found in this sample.

A December sample from Sandy Point, 4 miles below Ragged Point, showed a light plankton content. This sample was taken nearer shore, in about 14 feet of water. The preceding sample at Ragged Point was taken on the edge of the channel at a depth of 27 feet.

Only four genera of diatoms were found in the Piney Point sample. *Chaetoceros*, leading, with 4,200 standard units per liter, *Asterionella* (1,800), *Stephanodiscus* (600), and *Pleurosigma* (600) were the other genera. No blue-green algæ were present. The dinoflagellates *Ceratium* (1,800 per liter) and *Peridinium* (600) were found. *Codonella*

nd the crustacean *Cyclops* appeared, 1,200 and 900 per liter, re-pectively. A December sample taken in 12 feet of water near St. Georges Island showed an almost identical plankton content, the ame diatoms, the same dinoflagellates, and crustaceans. This point s 4 miles from Piney Point, on the same side of the river. Condi-ions seem to be similar at these two places, and this similarity is re-lected in the plankton content.

Two samples were taken in St. Marys River in January—one at he mouth of the river and the other 6 miles up the river, near the illage St. Marys. The channel at the latter place is about 18 feet leep. When the sample was taken (15 feet "vertical") the tempera-ure of the water was 2° and the turbidity was 12. Nine genera of liatoms were present in this sample. *Asterionella* (21,000 per liter), *Eunotia* (6,000), *Melosira* (5,000), *Synedra* (3,000), *Stephanodiscus* (2,000), *Navicula* (2,000), *Pleurosigma* (2,000), with *Pyxilla* and *Nitzschia* in smaller numbers per liter, comprised the list. Blue-green algæ were absent. A fragment of the filamentous green alga *Cladophora* was found. The dinoflagellate *Ceratium* (3,000), *Gleno-dinium* (2,000), and *Peridinium* (1,000), the infusorian *Codonella* (3,000), also a bottle-shaped *Tintinnus* (1,000), the rotifer *Synchaeta* (1,000), and the crustacean *Cyclops* (2,000) completed the count.

A 30-foot vertical sample was taken at the river's mouth on the ame day. Temperature and turbidity was the same as in preceding. *Asterionella* (21,600 per liter), *Cyclotella* (4,000), *Melosira* (3,600), *Stephanodiscus* (1,600), *Pyxilla* (1,600), *Pleurosigma* (1,200), with a few *Synedra* and *Himantidium* constituted the diatom content. A few dinoflagellates, *Ceratium* (1,200) and *Peridium* (2,400), were present, also a few *Codonella* and the bottle-shaped *Tintinnus* and a very few *Cyclops* of the crustacea.

One sample was taken in May at St. Georges Island. Temperature was 19.5°, turbidity 8. The diatom content consisted chiefly of *Melosira* (1,300 standard units per liter), *Stephanodiscus* (750), *Navicula* (750), and a few *Nitzschia*. No algæ of any kind were found. Dinoflagellates were again in evidence, showing 1,000 *Cera-tium* and 1,500 *Glenodinium*. The infusorian *Tintinnus* was present (750 per liter) and crustacea *Cyclops* (1,250, mostly young) and *Acartia* (250).

The preceding plankton data in general indicate an uncontami-nated water. The occasional presence of *Tintinnus*, of blue-green algæ, or of any other contaminate organism in small quantities does not signify that the water as a whole is contaminated. On the other hand, these samples show moderately large numbers of such organ-isms as are usually associated with water of good quality, diatoms, crustacea, and certain of the dinoflagellates. One of these related

forms, *Ceratium hirundinella*, was found by Kofoid[1] to be abundant in Lake Michigan, but it was apparently unable to endure the polluted waters of the Chicago River and Drainage Canal in transit to the Illinois River, hence its presence in small numbers in the latter stream.

Bottom samples.—Mud samples were dark to yellow in color, with little or no odor, and were composed chiefly of soft clay. One sample was slightly granular. The sand worm *Nereis* was found in all samples. A small crustacean, similar to *Ascellus*, appeared in a sample taken off Cherryfield Point, in the St. Marys River, near the mouth. Another mud sample, taken near Priest's Point, 3 miles up the St. Marys, contained four oligochaete worms, which probably indicated some organic matter introduced locally.

Mud taken from the Potomac Channel near Sandy Point was yellowish, without odor, and contained *Nereis*, a small fragment of a grasslike Potomageton, and shreds of plant tissue. Most of the river bottom in this locality is soft, a few places only being sandy or firm.

The evidence furnished by these bottom samples tends to confirm that already secured from the plankton, to the effect that the water is not contaminated.

DISTRICT IV.

Conditions here are essentially similar to those in District III, and for all practical purposes the two sections may be treated as one. The so-called Potomac River here unites with Chesapeake Bay, after passing between Smith Point and Point Lookout.

Plankton.—Two plankton samples were collected near the edge of the channel off Point Lookout in December. The water was clear, and temperature was 8.5°. A 13-foot vertical sample showed five genera of diatoms, *Chaetoceras*, with 16,500 standard units per liter, being most numerous. *Stephanodiscus* (4,100 per liter), *Pleurosigma* (2,150), *Asterionella* (1,500), and *Melosira* (1,500) were the other genera present. Dinoflagellates, especially *Ceratium*, were fairly numerous, this organism numbering 6,000 per liter, *Glenodinium* (750), and *Peridinium* (1,100). *Codonella* and *Tintinnus*, of the infusoria, were present in small numbers. The rotifer *Synchaeta* numbered 150 per liter and *Asplanchna* about 400. No crustaceans were observed in this sample.

A December sample, taken in 32 feet of water on the Virginia side of the channel (nearly opposite Point Lookout), contained a similar plankton. *Chaetoceros* again led the diatoms with 15,000 standard units per liter. *Stephanodiscus* (4,000), *Asterionella* (3,000), with

[1] Bull. Illinois State Lab. Nat. Hist., Vol. VIII, p. 72.

Synedra and *Pleurosigma* in small numbers were the other genera present. No blue-green algæ were found. A small amount of *Conferva* (unidentified) represented the green algæ. One dinoflagellate, *Ceratium*, was present in small amount, 500 per liter. *Codonella* (1,200), *Cyclops* (500); a few unidentified sporelike bodies, and a much contracted, unidentified organism, probably a rotifer, completed the list of plankton forms.

The plankton content at Point Lookout in May, 1914, showed considerable difference in the diatom population. The usually abundant *Chaetoceros* was absent. *Melosira* was abundant, there being over 28,000 standard units per liter. *Navicula* (10,000 per liter), *Stephanodiscus* (6,000), *Asterionella* (5,000), *Synedra* (7,000), *Pleurosigma* (3,000), and *Pyxilla* (1,000), were the other genera present. *Peridinium* (7,500 per liter), was the most abundant of the dinoflagellates. About 2,000 *Glenodinium* were also present. *Tintinnus* and *Codonella*, of the infusoria, numbered approximately 2,000 per liter each. A few *Cyclops*, chiefly young, were present, also unidentified sporelike bodies. The plankton content of these samples from District IV is, on the whole, reassuring as to the condition of the water. In no case are distinctly contaminate organisms present in such numbers as to justify suspicion. On the contrary, the prevailing organisms are those that are normally present in water of good quality.

Bottom samples.—Samples taken near the edge of the channel off Point Lookout and off Hog Island (the latter being on the Virginia side of the river) consisted chiefly of sand and gravel, the animal life of which was found to be the sandworm *Nereis*, a few oysters, and small univalve mollusks. Barnacles, sponge (a red variety), and *Bryozoa* were present in moderate numbers attached to pebbles and stones, and groups of Ascidians were found on various objects that furnished a suitable surface for attachment.

The only plant life found consisted of a few varieties of "seaweed" or marine algæ, all belonging to the group *Rhodophyceae*. No organic remains were found except oyster shells.

Five bottom samples taken by the mud scoop were examined; these were supplemented by contents of hauls made by the oyster dredge on board the Bratton. The evidence of the bottom samples, so far as observed, is in accord with the evidence furnished by the plankton, to the effect that no appreciable contamination is present.

SUMMARY.

The Potomac River consists of a narrow, rapid, "young" portion—the Upper Potomac—and a wide, slowly flowing tidal portion—the Lower Potomac. The Lower Potomac consists of a deep channel

and extensive shallow flats, which contain much submerged plant life in summer.

The tides thoroughly mix the water of the channel and of the flats; they reverse the normal current for a time, greatly increasing the time required for water to reach a given point downstream. This has the effect of increasing the length of the river.

The sewage of Washington is pumped into the river channel 3 miles below the city. Alexandria sewage also enters the river, part of it flowing first upon a large flat. The possibility of this sewage resulting in harm to the fishing industries and oyster beds of the lower river is one reason for the present investigation to determine the ultimate fate of this sewage, and to ascertain the various related biological forces concerned in its disposal.

Weekly samples were taken at selected stations when possible. Weather conditions, ice, and extreme turbidity of water interfered with the regularity of collections.

Collecting stations were chosen with reference to existing biological factors, such as absence of sewage, presence of plant life, distance from the main sewer, influence of the flats, results of tidal movements, effects of sunlight, presence of sewage, and effects of turbidity and temperature. Samples were taken on the flats for the determination of dissolved gases. These were in addition to plankton, mud, and biological samples. Careful observation was made in the field of biological conditions prevailing from time to time. Samples of major plant life (submerged) were collected. A record of local weather conditions was kept daily, in order to note the relative effects of cloudy and sunny days and of rain and wind on the plankton organisms or on their environment.

Plankton from the channel at Three Sisters, above Washington, shows the presence, on the whole, of few organisms indicative of contamination. The occasional presence of certain contaminate forms is likely due to slight local contamination by overflow of canal water, or to flood conditions. The organisms present continuously and in greatest numbers are those characteristic of water of good quality.

The water at Giesboro Point, 5 miles below Three Sisters, has received a limited amount of polluting material from the canal, from wharves along the water front, from storm water sewers, and, occasionally, from the main sewer outlet by combined flood tide and wind. This contamination is reflected in the plankton content by the persistent presence of blue-green algæ, together with the flagellate *Euglena viridis* and certain infusoria whose normal habitat is polluted water. Bottom samples showed many tubificid worms, and a few *Chironomus* larvæ. The former organisms are usually characteristic of pollution.

The water at Fort Foote is affected by (1) addition of sewage, (2) checking and reversing of current by tides, (3) mixing with water on flats, (4) activity of submerged plants, (5) long sedimentation and general readjustment of water on flats. Plankton samples show varied organisms consistent with the variety of factors affecting the water. The persistent presence of contaminate plants and animals attests the presence of sewage, but comparatively small numbers of these organisms indicate the effective disposal of much of the sewage. Various organisms diminish in number with the advent of cold weather, and become numerous again when warm weather returns. The character of the bottom mud, together with the contained animal life, indicates impure water.

Marshall Hall, 12 miles below the sewer outlet, is about four days below, in terms of time, because of tidal action. The water has been exposed to 16 tides and to the effluent from over 6 square miles of flats, on its 100-hour trip from the sewer outlet.

The volume of water is increased. Plankton organisms reflect this improved environment, contaminate forms being very few and pure-water forms moderately abundant. Mud samples show improvement in general character and in animal content.

A typical flat was studied to ascertain whether it constituted a benefit or an injury to the river. Some factors concerned were: (1) Presence of plankton and of mud organisms, (2) dissolved gases, (3) activity and decay of submerged plants, (4) results of tides, (5) effects of winds and sunlight, (6) fate of sewage entering a flat, (7) effects on water due to the flat as a delay station.

Hunting Creek flat was thus studied. Its area is $1\frac{3}{10}$ square miles, with a river frontage of $1\frac{1}{4}$ miles. It has a heavy growth of submerged plants. The average tide is 30 inches. A sewer discharges on the flat. It is drained by a small dredged channel and by a broad natural channel. Samples (plankton, mud, dissolved gases, and bacteria) were taken at points illustrative of (1) sewage contamination, (2) mid-flat or average conditions, (3) final condition of water as it ebbed back to the channel.

A moderate number of contaminate organisms is present in the water in the vicinity of the sewer. In mid-flat these organisms are fewer in number. At the point where the water ebbs from the flat to the river channel the contaminate organisms are again moderately abundant, probably due to tidewater from the river channel. The character and inhabitants of the bottom mud are in accord in every case with the evidence furnished by the plankton.

Many factors involved in dissolved oxygen and free CO_2 content of water also affect, directly or indirectly, plankton life. In the vicinity of the sewer on the flat dissolved oxygen is lowest and free CO_2 is highest; bacterial counts also are highest here. In mid-flat

dissolved oxygen is higher and CO_2 lower, as a rule, than in the vicinity of the sewer. As the water ebbs from the flat it is still higher in dissolved oxygen than the water in river channel. The high dissolved oxygen of water on the flat seems to be due partly to the synthetic activity of submerged plants in the presence of sunlight and absence of turbidity, the average per cent of oxygen saturation on sunny days being 103 and on cloudy days 75.

The effect of sunlight on activity of plants on the flats is noticeable in the water of the adjacent river channel, this being higher in dissolved oxygen on sunny days than on cloudy days. This difference is not apparent at Three Sisters, where plant life is not a factor. The dissolved oxygen of ebb-tide water taken in the afternoon is higher than that of samples taken in the forenoon. This is seemingly due to a longer period of synthetic plant activity.

Tidal action, forcing large amounts of water on the flats and withdrawing it regularly, similar to the movements of air in the lungs, is largely responsible for the long period of readjustment to which much of the water is subjected.

Hunting Creek, with an area of 1.3 square miles, under conditions obtaining in October and November, produced, by biologic means, sufficient oxygen for the complete oxidation of a portion of Alexandria's sewage and of 6,000,000 gallons per day of Washington's sewage. Considering only the first 24 hours' oxidizing reaction, this flat produced oxygen sufficient to care for 30,000,000 gallons of Washington sewage daily in addition to the complete oxidation of the portion of Alexandria's sewage.

Plant life on the flats apparently decays slowly and produces little or no change in the dissolved oxygen content of the water. This may be due (1) to circulation enforced by tides, (2) to production of oxygen by activity of microscopic plants, especially diatoms and algæ. Experiments furnish evidence in accord with the latter.

In the early spring mud is disturbed on shallow flats by water agitated by wind, producing a much higher turbidity than is present in channel water at the same time. In summer and fall conditions are reversed, submerged plants protect the mud, and the turbid water of the channel does not penetrate far into the flat. Sewage discharged on the flat has nearly disappeared when water ebbs into the river channel, three-fourths of a mile away. Present data concerning this matter are insufficient.

The lower 60 miles of the Potomac have the characteristics of an estuary. Relatively few plankton samples were taken, as there was scant evidence of contamination.

In District I, 40 miles in length, the water becomes brackish, and most of the mud in suspension settles or is precipitated. Peridinium

appears in the plankton here. The evidence of the plankton is to the effect that the water is not contaminated. Evidence furnished by mud samples is less favorable, but indicates only slight contamination.

District II is in the fishing and oyster dredging territory. Neither plankton nor mud gives evidence of contamination of water. Organisms characteristic of good water are abundant.

District III is well in the lower part of the estuary. Plankton shows many genera of diatoms, including *Chætoceros*. Contaminate organisms are absent, both from plankton and from mud.

District IV is the region at the mouth of the lower river. The deep, clear, brackish water gives no adequate evidence, in plankton or mud, that contamination is present.

CONCLUSIONS.

1. Certain organisms, both of the plankton and of the bottom mud, are prevalent in those parts of the river where sewage is discharged, but are not prevalent in the unpolluted part of the river above Washington nor in the lower estuary portion. These organisms gradually but surely disappear in proportion as time and distance increase down the river from the place where sewage enters the water. The plankton life about 50 miles below Washington indicates as good a water as that at Three Sisters.

2. The abundance of certain organisms means not only the presence of sewage, but also the disposal of much of it, because of the establishing of certain links in the various chains of food relations. Certain animal forms especially are rarely found in clean water, but are abundant in polluted water. These organisms must find in such water the food they require. Some are evidently scavengers. Others are known to be omnivorous or carnivorous, the larger preying on the smaller; but this must come to an end somewhere, else microscopic life would cease. There must be an adequate food supply for the swarms of smaller organisms that are eaten by the larger; also there must be a connecting link between the nonliving dissolved organic matter, on the one hand, and, on the other, the smallest of those organisms whose habits start the "chain of food relations." There is reason to believe that bacteria and other minute plants occupy the important position of this connecting link by utilizing the dissolved organic matter and by becoming in turn the food supply of minute organisms.

3. This possible destruction of bacteria by certain plankton organisms may help to explain the sudden decrease, at times, in the bacterial count. The activity of these larger organisms may also be a factor in the frequent discrepancy between the large amounts of organic matter disposed of and the resulting small amounts of nitrates

finally formed by bacterial action, as some of these plankton forms apparently find much of their food in the sewage itself, instead of in sewage bacteria. We can not know the full significance of these organisms in water and mud until we have accurate and complete knowledge of their food habits.

4. Volume of plankton, irrespective of kinds of organisms composing it, does not necessarily imply presence of sewage or absence of it. Inspection of Table 28 shows that the volume of plankton at Three Sisters is less than at other stations and that the volume is greatest in the unpolluted water of the Potomac Estuary, near Chesapeake Bay. This abundance is evidently due to the gradual admixture of salt water, as some of the organisms are marine forms.

5. The effect of the time factor, together with adequate food supply, is evident in the increased plankton content at Marshall Hall, where the volume of plankton is twice as great as at Three Sisters. This increase is probably due to the delay on the flats, together with food introduced by sewage, as many of the organisms are sewage forms. The plankton at Three Sisters has neither the time factor provided by delay on the flats nor the food furnished by sewage.

6. The flats are effective as breeding places for plankton, the average volume per cubic meter of water being more than twice as great as is found in the adjacent river channel. These average volumes are shown to be 3.64 c. c. for the flats and 1.60 c. c. for the adjacent river channel.

7. In summer the flats are vast "balanced aquaria," with a surplus of dissolved oxygen. In fall and early spring they are integral parts of the river on account of tidal action. Throughout the year they are valuable delay stations for the water. As an asset to the river they are second only to the tides in importance.

8. The flats undergo a sort of annual "house-cleaning" process in the spring, when the ice goes out, carrying any accumulated débris with it. For several weeks the spring winds agitate the shallow water and stir up the surface mud. When this again settles it has been exposed to long contact with well-aerated water. The cleansed flat is now ready for another season's work as a purifying delay station.

9. Examination of plankton and mud from the Potomac Estuary shows the presence of a very few doubtful contaminate organisms and indicates that this water is in better condition, as to sewage contamination, than the average water at Three Sisters, just above Washington.

10. The character of the bottom mud does not fluctuate as widely nor as suddenly as does that of the water above it. Being more stable, it is a valuable index of the average condition of the water. It is a

depository of evidence and a resultant of the prevailing factors that affect the water. Almost invariably the evidence of the bottom mud is in accord with that furnished by the plankton, and its study is equally important.

11. The tides, the flats, and in summer the submerged plants on the flats constitute the triumvirate of purification of Potomac water. The tides dominate the situation by producing thorough mixing of sewage and water, increasing by many times the effective length of the river and providing a very long time factor for the activity of organisms, and by compelling frequent and thorough circulation of channel water with that on the flats. The latter are thus made integral parts of the river, and they become most useful allies, instead of the semistagnant bayous they would probably be if the river were tideless.

POTOMAC SHELLFISH.

Oysters in the lower reaches of the Potomac River form the basis of a large and important industry. Large numbers of men gain a livelihood from this source, and the product is shipped, chiefly through Washington and Baltimore, to many diverse parts of the country. In order to protect this industry, as well as to protect the ultimate consumers of the oysters, it is essential that the sanitary quality of the shellfish be known, and when necessary improved and protected.

The oyster beds extend from the mouth of the river about halfway to the city of Washington. In the upper few miles they are used almost solely for the growth of spat, and the oysters developing here are used chiefly for planting the lower beds and rarely reach marketable size.

From data on pollution and purification of the river detailed in the preceding sections it is evident that by the time the water reaches the area of the oyster beds it has undergone its maximum purification. Although during the winter months the increased stream flow shortens the time during which purifying agencies may act, any anticipated danger of pollution of shellfish from this cause will be shown to be without foundation.

The method of collecting samples of oysters and recording the specimens has already been referred to (p. 78).

Procedure followed in examination of shellfish.—The procedure used for the examination of shellfish and for scoring the results obtained was that recommended by the American Public Health Association at its meeting in 1912. The score or rating, according to this method, is calculated by adding the reciprocals of the highest dilutions in which *B. coli* has been found in the shell liquor of the five oysters which form the specimen. Thus, in the shell liquor of five oysters separately examined, *B. coli* has been found in three in the 0.1 c. c. dilution and in two in the 1 c. c. dilution. The reciprocals are 10, 10, 10, and 1, 1, and their sum is 32—the rating.

The oysters were removed from the bag, thoroughly scrubbed with tap water, which is here practically free from bacteria. They were then wiped dry, seized with rat forceps, and flamed, to eliminate all danger of contamination from without. The oyster was then carefully opened with a narrow-blade stabbing oyster knife, which had also been passed through a flame. The samples taken on the steamship *Bratton* were scrubbed at once in the water from which they were taken and then flamed and opened.

Bacterial counts were made of a composite sample, made by mixing equal quantities of the shell liquor of each of five oysters, plated in various amounts in nutrient agar, which was incubated at 20° for three days, and then counted. The qualitative determination of the *B. coli* group was made by placing measured quantities of liquor from each of five oysters of the sample in fermentation tubes containing lactose peptone bile or broth, and, in a large proportion of the samples taken, parallel series were run in both of these media for the purpose of determining their relative values. The fermentation tubes were then incubated for three days at 37° and gas formation noted. From the highest dilution showing gas and from the lowest showing no gas, Endo plates were then inoculated for confirmatory tests. Samples of the water from over the oyster beds were taken at the same time as the oysters and analyzed in the manner previously described.

The water used for dilution purposes in the examination of oysters contained 1 per cent of sodium chloride in order to approximate the natural salinity of the oyster liquor. In addition to this, however, a number of parallel dilutions in distilled water were plated for comparison. A higher count was invariably obtained from the saline dilutions.

Samples of oysters for bacteriological examination were taken at frequent intervals during the period from November 25, 1913, to May 26, 1914 (fig. 27). Certain stations were established throughout the areas from which oysters are taken for general consumption and carefully located in order that the samples might be taken from approximately the same places on each occasion. An effort was made to secure a considerable number of examinations of oysters from all the principal oyster bars in the Potomac River throughout the season. The samples were collected by the crew of the sample boat, and the tubing and plating were done at the moment the oysters reached the laboratory, seldom more than three or four hours after being taken from the water. Samples of water at a depth of 2 feet and on the bottom were taken over the oyster beds with nearly every sample of oysters and examined at the same time with it.

RESULTS OF BACTERIOLOGICAL EXAMINATION OF OYSTERS.

General results.—The results of bacteriological examination of the oyster specimens will be found in Table 39. Attention is drawn to the low average score in general. In Table 40 the results of simultaneous examinations of oysters and the overlying water for 12 representative stations are given, these stations having been selected for making certain comparisons. It will be noted that the *B. coli* content of the oysters does not bear a constant relation to that of the water immediately

overlying the bed. With but few exceptions, the average for the water is higher in January and February than in any other months, while in every case the oysters contain fewer colon bacilli during these months than they do in April and May. This divergence of the *B. coli* content of the water from that of the oysters coincides with the observations of Gorham and others in this respect. The seasonal variation in the *B. coli* content of the oysters is therefore independent of that in the surrounding water and to an extent opposite in direction, being more nearly correlated with the temperature. From these and other observations it has been deduced that during cold weather the functional activities of oysters become reduced, and that much less water is passed through them in a given time period. The above figures remove the apprehension lest in the period of delayed purification of the river water an increased contamination of the oysters might take place.

TABLE 39.—*Summary of the results of the analyses of oysters, arranged by stations.*

Station from which oysters were taken.	Number of samples.		Average score.		Maximum score.	
	Broth.	Bile.	Broth.	Bile.	Broth.	Bile.
Popes Creek, Md., 150 yards northwest of wharf	12	6	2.5	1	14	2
Paspahanza Creek, 150 yards offshore	10	5	3.9	.4	4	2
Lower Cedar Point	17	8	5.5	1	32	5
Piccowaxton Creek, Md	3	1	1.7	2	14	2
Cuckold Creek, Md	7	3	.1	1.3	3	3
Swan Point	15	11	6.2	.5	50	2
Swan Point Creek:						
50 yards offshore	5	1	9.8	1	41	1
500 yards offshore	0	1	....	1	....	1
1,000 yards offshore	1	1	0	0	0	0
Kettle Bottom, between Swan and Bluff Points	1	1	0	3	0	3
Neal Creek, off buoy 14	7	3	5.3	0	32	0
Cobb Point Bar:						
50 yards off Beacon No. 42	1	2	2	3	2	3
100 yards off Beacon No. 42	8	7	1.8	1	5	5
Wicomico River samples.						
Opposite St. Margarets Island, off mouth	9	7	1.1	1.1	3	3
Shipping Point	1	1	2	3	2	3
Bluff Point	1	1	3	1	2	1
Rock Point Bar buoy No. 6	2	1	1.5	2	2	2
Lancaster Wharf:						
50 yards off	1	0	1	0	2	0
200 yards below	1	1	1	0	1	0
Kanzalo Bar, off Bushwood	1	1	3	2	3	2
Startletts Bar, off Bushwood	1	1	3	2	3	2
Charles Point	2	1	8	.5	14	1
Key Bar	1	1	1	1	1	1
Lumps in channel (Wicomico lumps)	1	1	1	0	1	0
Roats	1	1	4	2	4	2
St. Catherine Island Sound, off Chisel Time Bar, 50 yards off dock	3	3	3.7	9	4	23
Sheepshead Bar, near red buoy 6	9	8	2	2.1	5	14
St. Clements:						
Samples off Coltons Wharf	5	3	1.8	2.3	4	3
Off mouth	2	2	20	25	40	50
Blovers Cove	2	2	25.5	26.5	50	50
Cobrums Wharf	3	2	14.3	21	41	41
Upper end of St. Clements	1	0	3	0	3	0
Higgins Point, off red buoy 2	7	3	1	1	2	3

TABLE 39.—*Summary of the results of the analyses of oysters, arranged by stations*—Continued.

Station from which oysters were taken.	Number of samples.		Average score.		Maximum score.	
	Broth.	Bile.	Broth.	Bile.	Broth.	Bile.
Bretons Bay samples.						
Bretons Bay, mouth of	1	1	3	0	3	0
Protestant Point	3	2	1.3	1.5	2	3
Lovers Point	3	2	1.7	1.5	4	2
Piney Point	18	16	.6	.4	3	3
Off St. Georges Island	18	16	.3	.4	2	3
St. Marys River samples.						
Cherry Field Point	1	1	0	0	0	0
Priests Point	3	2	2	2.5	3	4
St. Marys, 50 yards offshore	2	2	1	1.5	2	2
Smith Creek:						
Off red beacon	2	2	.5	.5	1	1
In creek	2	2	.5	2.0	1	4
Cornfield Point, Md	16	14	.7	.4	3	2
Point Lookout, Md	14	12	1	1	4	4
Coan River, Va., samples.						
Entrance near Beacon	1	1	14	0	14	0
300 yards south of Lewisetta, near Beacon	1	1	23	5	23	5
Cowerts Wharf	2	1	176	0	320	0
200 yards above Walnut Point Wharf	1	1	0	23	0	23
Off Hog Island	13	11	2.9	.8	......	......
Yeocomico River samples.						
Off entrance, Beacon	......	1	......	0	......	0
Off Mundy Point	1	1	4	0	4	0
Off Mundy Point, ½ mile	......	1	......	0	......	0
Below Kinsale Wharf (Baileys)	1	......	5	......	5	......
Off Kinsale Wharf	......	1	......	23	......	23
Lynchs Point	11	10	.6	1	4	2
Ragged Point, off lighthouse	13	12	3.1	.7	32	3
Machodoc River, ½ mile off entrance	2	2	25	20.5	50	41
Machodoc River, off Narrow Beach	2	2	9.5	14	14	23
Kingcopsico Point, Va., 500 yards offshore	2	2	11.5	25	23	25
Nomini Creek, Va., samples.						
Above Dietricks Wharf, 200 yards	2	2	21.5	21.5	41	41
Deep Point	1	......	23	......	23	......
Deep Point, 100 yards down	1	1	4	0	4	0
Nomini Cliffs, 100 yards offshore	9	9	1.2	.7	5	4
Popes Creek, Va., off Washington Monument, 25 yards from shore	13	8	5	3.75	32	2
Wakefield, 100 yards offshore, south of pier	15	10	1.5	1.4	5	4
Old Farm, 250 yards off steel pier	4	3	5.5	2.3	14	4
Haywood Breaks, between Wakefield and Church Point, 100 yards offshore	12	8	5.25	2.25	32	14
Church Point, Va	8	4	5	2	23	5
Mattox Creek, Va	10	6	6.5	1.6	32	......
Monroe Creek, Va.:						
800 yards off	17	12	1.4	2.7	4	13
20 yards off sewage plant	8	3	11.8	1.7	50	1
Gum Bar	1	1	1	1	1	4
Colonial Beach, 500 yards off stone house	17	10	2.5	5.0	14	41
Watsons Bar, 100 yards off Watson's cottage	5	1	1	14	4	14
Off Classic Shores, southeast of Bluff Point	4	4	0	0	0	0
Bluff Point, Va	6	4	1	1.5	3	3

TABLE 40.

WAKEFIELD, VA.

Months.	Number of samples.	Average score.	Average temperature.	Average B. coli per c. c. in water over bed.	Average agar count at 20° (oysters).	Months.	Number of samples.	Average score.	Average temperature.	Average B. coli per c. c. in water over bed.	Average agar count at 20° (oysters).
			°						°		
December...	......	......	......	......	......	March.......	2	0.50	3	0.02	3,000
January.....	6	1.5	3	0.36	2,800	April.......	3	1.3	13.3	.05	6,000
February...	1	0	3	.05	5,200	May........	4	3.2	19	.04	17,600
WATSON BAR.											
December...	......	......	......	......	......	March......	......	......	......	......	......
January.....	......	......	......	......	......	April.......	4	0.5	11	0.07	13,400
February...	4	0	3.2	0.17	21,200	May........	2	9.0	19	.10	9,300
MONROE CREEK.											
December...	......	......	......	......	......	March......	......	......	......	......	......
January.....	1	5.0	5	1.0	27,500	April.......	3	3.7	13.3	0.07	63,000
Eebruary...	1	2.0	5	.55	......	May........	4	20	19	.66	104,700
COLONIAL BEACH.											
December...	5	1.8	8	0.14	4,200	March......	......	......	3	......	......
January.....	2	2.5	2.5	.30	12,800	April.......	3	7.0	13.3	0.22	7,300
February...	3	1.0	3.7	.40	13,200	May........	5	13	19	.14	12,500
SWAN POINT.											
December...	2	2.5	8.5	0.05	1,500	March......	1	0	......	......	10,000
January.....	4	6.0	2.5	.27	8,500	April.......	3	17.0	99	0.03	6,900
February...	4	1.0	2.2	.27	2,300	May........	3	1.3	19	0	37,700
800 YARDS OFF MONROE BAY.											
December...	3	2.0	8	0.07	9,400	March......	1	0	1	1.00	3,900
January.....	6	2.1	4	.38	11,800	April.......	3	1.7	13.3	.07	6,000
February...	1	0	1	.05	1,900	May........	5	5.0	19	.06	7,800
MATTOX CREEK.											
December...	......	......	......	......	......	March......	2	2.0	2.5	0.05	8,600
January.....	1	5.0	5	0.55	1,000	April.......	3	7.0	13.3	.03	9,300
February...	1	0	5	.10	......	May........	5	6.5	19	.14	14,000
HAYWARD BREAKS.											
December...	......	......	......	......	......	March......	2	0	2.5	0.03	2,400
January.....	1	2.0	5	0.55	22,500	April.......	3	8.3	13.3	.03	10,200
February...	3	.33	3	.37	4,900	May........	5	9.8	19	.17	71,000
LOWER POPES CREEK.											
December...	......	......	......	......	......	March......	3	1.0	3	0.03	4,100
January.....	1	1.0	5	0.55	50,000	April.......	3	8.6	13	.03	17,000
February...	3	1.0	4	.40	18,500	May........	4	8.7	19	.02	20,000

TABLE 40—Continued.

SHEEPSHEAD BAR.

Months.	Number of samples.	Average score.	Average temperature.	Average B. coli per c. c. in water over bed.	Average agar count at 20° (oysters).	Months.	Number of samples.	Average score.	Average temperature.	Average B. coli per c. c. in water over bed.	Average agar count at 20° (oysters).
			°						°		
December	3	2.3	7.7	0.07	17,000	March	......	......	......	......	......
January	3	0	3	.01	2,000	April	1	4.0	14	0	9,900
February	1	0	2	0	2,200	May	3	7.3	19	0	24,500

HIGGINS POINT.

Months.	Number of samples.	Average score.	Average temperature.	Average B. coli per c. c. in water over bed.	Average agar count at 20° (oysters).	Months.	Number of samples.	Average score.	Average temperature.	Average B. coli per c. c. in water over bed.	Average agar count at 20° (oysters).
December	4	1.7	7	0	8,800	March	......	......	......	......	......
January	1	0	5	0	800	April	1	1.0	14	0	6,300
February	......	......	......	......	......	May	2	2.5	19	.05	20,000

LOWER CEDAR POINT.

Months.	Number of samples.	Average score.	Average temperature.	Average B. coli per c. c. in water over bed.	Average agar count at 20° (oysters).	Months.	Number of samples.	Average score.	Average temperature.	Average B. coli per c. c. in water over bed.	Average agar count at 20° (oysters).
December	6	4.5	7	0.03	5,000	March	......	......	......	......	......
January	......	......	......	......	......	April	5	1.8	12	0.12	22,800
February	3	1.3	4	.10	18,700	May	3	4.0	19	.05	12,700

General averages of above stations by months.

Month.	Number of samples.	Average score.	Temperature (°).
November	7	0.3	11.0
December	23	.6	8.0
January	26	.9	2.5
February	25	.26	3.7
March	11	.3	3.0
April	35	1.7	13.3
May	43	2.1	19.0

Samples giving high scores.—It is of interest to examine more closely the samples which gave high scores on examination. Seventeen of the 461 samples collected in the river and its tributaries gave a score of 32 or over. Of the 17 samples, 3 had a score of 41, 5 had a score of 50, and but 1 had a score of over 50. While a score of 32 was formerly regarded by some persons as the upper limit of safety, this figure has been raised to 50, and such a rating is now generally considered to be a safe one. The six samples scoring 50 or more will therefore be considered.

The sample from near the mouth of St. Clements Bay, which scored 50 in broth and 40 in bile, was taken January 29, the tide being ebb, the water 4.8°, depth of water 18 feet, salinometer reading 1.0095. The oysters of this lot, which scored 50, were kept for 96 hours on the boat and in the incubator at 15°. Other oysters of the same lot examined at once gave a total agar count of 700 and a score of 0 on both bile and broth. The samples from Cobrum's wharf, which gave a score of 41, and the one from Blovers Cove, which gave a score of 50, were also kept for 96 hours with the St. Clements Bay sample. Oysters of the same lot from Cobrum's wharf, examined immediately,

gave a total agar count of 9,300, a score of 0 in broth, and 1 in bile. Oysters from the same lot as those from Blovers Cove when examined immediately gave an agar count of 9,300 and a score of 1 in broth and 3 in bile. Both lots were taken January 29, the tide being flood, the temperature being 6.2° and 4.5°; depths, 6 feet and 8 feet; salinometer reading, 1.012.

The flats and Blackistons Island prevent any considerable amount of water from passing from the Potomac to St. Clements Bay on an ebb tide. The pollution when present is probably due to local sources, from farms, and the few houses on the shores.

The samples from off Machodoc River, which gave a score of 50, were also kept for 96 hours, and oysters of the same lot analyzed immediately gave a score of 0 in broth and bile with an agar count of "spreader." The samples from Coan River, off Cowarts wharf, were analyzed at once. They were taken May 20, after the oyster season was over. At Lewisetta there is a large fish factory only a few hundred feet from this bed, as well as a group of several houses; the pollution was evidently local. Oysters from this immediate vicinity are certainly undesirable during the season when the factory is at work, which fortunately is not coincident with the oyster season of Virginia.

The sample taken May 15 about 20 yards off the mouth of the outfall of the Colonial Beach sewage-disposal tank, in Monroe Bay, scored only 50, probably owing to the small amount of sewage at that time of the year and the great dilution; though of nine other samples taken at that point only one scored as high as 23. While it is true that this tank, during the period from September 1 to July 1 of each year, receives such a small amount of sewage that there is little effluent, the potential danger here is too great and it is quite evident that such a bed should not be used.

The Swan Point sample, taken April 30, which gave a score of 50, and the one from Swan Point Creek, taken the same day, which gave a score of 41, were the only samples, out of the 65 taken above a line from Colonial Beach to Swan Point, which gave over 32 score; they were taken on a flood tide, with a temperature of 17°, and were probably due to local field wash. While these samples from Swan Point were taken about the time when the high freshet from the upper river would have its maximum effect in the river below Cedar Point, the bacterial results obtained from water taken over the beds showed *B. coli* absent in each of two 10 c. c. samples, and the total counts were only 40 in the top and 34 in the bottom, sample on agar, and only 240 in the top and 230 in the bottom, sample on gelatin.

One of the 18 samples taken at Lower Cedar Point cross section gave a score of 32 on a flood tide, with temperature of 21°, but no other samples scored over 5. The higher score may have been due to

purely local pollution. The high score samples have been brought together in Table 41.

Of the 461 samples, of 10 or more oysters each, taken from the beds of the Potomac River or its tributaries, the following had scores of 32 or more, according to the method recommended by the Committee of the American Public Health Association. The score given throughout is the higher, whether from broth or bile media.

TABLE 41.—*Samples of oysters which scored 32 or more.*

Station from which taken.	Date.	Tide.	Temperature.	Score.	Media.	Total count agar at 20°.	B. coli in water over bed at time taken.
P tomac River:			°C.				c. c.
Lower Cedar Point	Dec. 13	Flood.	7	32	Broth	5,100	− in 10
Swan Point	Apr. 30	...do...	17	50	...do	7,400	− in 10
Swan Point Creek	...do	...do...	17	41	...do	7,400	− in 10
Neal Creek, 25 yards off buoy 14.	...do	...do...	17	32	...do	46,000	− in 10
St. Clements Bay, off Cobrum's wharf.[1]	Jan. 29	...do...	6.2	41	Broth and bile	57,000	− in 10
St. Clements Bay, near mouth.[1]	...do	Ebb	4.8	50	Bile (broth 40)	74,000	− in 10
St. Clements Bay, Blover's Cove.[1]	...do	Flood.	4.5	50	Broth and bile	600,000	− in 10
Coan River, off Cowart's wharf.	May 20	...do...	....	320	Broth	1,200	− in 10
Do	Mar. 10	Ebb	3.5	32	...do	6,400	− in 10
Coan River, off Hog Island	Mar. 11	Flood.	2.8	32	Broth (bile=5)	16,000	− in 10
Ragged Point Light	...do	...do...	2	32	Broth (bile=3)	8,100	+ in 10
Nomini River, between Dietrick's wharf and Mount Holly.[1]	Jan. 29	...do...	6.5	41	Broth and bile	42,500	− in 10
Machodoc River, one-half mile of entrance.[1]	...do	Ebb	5.4	50	Broth (bile=41)	8,600	− in 10
Popes Creek, Va	May 15	...do...	19	32	...do	40,000	− in 10
Haywood Breaks, Va	...do	...do...	19	32	...do	30,000	− in 10
Mattox Creek, Va. (private bed).	...do	...do...	19	32	...do	24,500	− in 10
Monroe Creek, 20 yards off sewage-disposal plant outfall.	...do	...do...	19	50	...do	100,000	+ in 10

[1] The samples kept 72 hours or more in incubator at 15° before being analyzed.

Pollution from excreta of men taking oysters from beds.—In no case, therefore, was any evidence discovered tending to show that high scores in oysters were due to contamination of the river water introduced at any point above the oyster-bearing area. Since there are at times several hundred men in boats over the beds engaged in taking oysters the possibility of contamination of the latter by excreta discharged into the stream must be considered. In Table 42 the number of men and boats occupied in dredging oysters according to accurate observations carried out during the investigation is given, and in Table 25 these numbers, expressed in daily averages, are compared with the colon bacillus content of the water for the same periods. No correlation is apparent, and the higher *B. coli* counts for January and February have already been amply accounted for by the increased stream flow and shortening of the time allowed for purification. The volume of water at these points is so great and the pollution added so scattered that dangerous contamina-

tion of this source can safely be eliminated. It is believed also that very little pollution is added to the stream over the beds in the main river, since it is customary for the oystermen to attend to these matters after retiring to the inlets and tributaries, which they do at night for the safety of their boats.

TABLE 42.—*Approximate number of vessels and men engaged in dredging oysters on the lower Potomac River from Nov. 1, 1913, to Mar. 15, 1914, inclusive.*

STATIONS AND VESSELS.

Date.	Swan Point.	Cobb Bar.	Wicomico.	Sheepshead.	Higgins Point.	Heron Island.	Lower Cedar Point.	Chisel Time.	Nomini Cliffs.	Coltons.	Total number of vessels.	Total number of men.	Remarks.
Nov. 3	15										15	75	
4		16	10	12	4	9				24	75	316	
5													No boats in vicinity of cruise.
6	16	3	20		18	24				21	102	529	
7	10										10	50	
8		7	16	16							39	234	
10													Do.
11													Do.
12		30		40	8	30		4			112	726	
13													Do.
14		37	10	26	9	9					91	464	
15		30		75	17			20			142	328	
17	24										24	192	
18		30	10	30	10	9		20			109	522	
19	20						10				30	220	
20		8	4	52	30	4		10	9		117	698	
21													Do.
22	10	10		100	4	10					134	967	
24													Do.
25	30	15		30	5	10					90	585	
26													Do.
28	30	40	5		8	5					93	674	
29	25										25	150	
Total											1,208	6,430	

Date.	Swan Point.	Cobb Bar.	Wicomico.	Sheepshead.	Higgins Point.	Colonial Beach.	Heron Island.	Lower Cedar Point.	Chisel Time Bar.	Nomini Cliffs.	Total number of vessels.	Total number of men.	Remarks.
Dec. 1	30	30	10	40	20	12					142	918	
2	25							20			45	220	
3													No trips made on the following days: 5th, 7th, 11th, and 14th.
4	35			40				60			135	700	
5	20	30	5	35	10	6	10		5	9	130	700	
6	15					12		20			47	160	
10	5					2					7	40	8th and 9th very rough.
12	20	10	10	40	10	3	9		10	15	127	600	
13	35										35	160	
15	50	12	3	10		5					80	520	No oyster boats could be seen.
16	25					5		14			44	260	
17										20	20	160	
18	15	10	5	20					3	4	57	350	
19	30							24			54	320	
20	20					5		10			35	210	
29	28					8		11			47	265	
30	20	15	10	10		5			3	3	66	385	
31	15					8		10			33	165	
Total											1,104	6,133	

TABLE 42.—*Approximate number of vessels and men engaged in dredging oysters on the lower Potomac River, etc.*—Continued.

STATIONS AND VESSELS—Continued.

Date.	Swan Point.	Cobb Bar.	Wicomico.	Sheepshead.	Higgins Point.	Colonial Beach.	Lower Cedar Point.	Nomini Cliffs.	Old Farm.	Bluff Point.	Lower Pope Creek.	Haywood Breaks.	Total number of vessels.	Total number of men.	Remarks.
Jan. 2	15	10	5	....	....	10	....	3	5	....	3	3	54	300	1st, 3d, 4th, 5th, 9th, 10th, 11th, 13th, 14th, 18th, 23d, 24th, 25th, 29th, no trips.
6	15	....	....	....	....	....	20	....	....	5	....	....	40	240	
7	10	5	3	10	2	8	....	5	8	....	5	5	61	350	
8	25	....	....	....	....	....	18	....	....	10	....	....	53	300	
12	3	....	....	....	....	....	....	....	2	....	....	....	5	25	Very rough.
15	10	3	8	3	1	....	....	6	10	....	6	12	59	300	
16	25	8	10	5	....	10	....	8	12	....	3	1	82	420	
17	....	....	....	....	....	....	6	....	....	....	....	....	6	42	
19	10	2	5	2	....	6	....	5	12	....	3	5	50	275	
20	12	5	....	....	3	1	....	....	....	....	....	....	21	100	
21	....	....	....	....	....	....	12	....	....	7	....	....	19	110	
22	18	7	3	....	....	3	....	3	14	....	6	1	55	320	
26	15	....	....	....	....	....	12	....	....	3	....	....	30	180	
27	8	3	1	6	1	1	....	6	12	....	3	2	43	240	
28	8	....	....	....	....	....	18	....	....	....	....	....	26	140	
30	15	....	....	....	....	....	....	....	11	....	14	5	45	250	
31	....	....	....	....	....	....	....	....	8	....	....	....	8	50	Do.
Total	....	....	....	....	....	....	....	....	....	....	....	....	657	3,642	

Date.	Swan Point.	Cobb Bar.	Wicomico.	Colonial Beach.	Lower Cedar Point.	Nomini Cliffs.	Wakefield.	Old Farm.	Bluff Point.	Lower Pope Creek.	Haywood Breaks.	Off Neal Creek.	Off Cuckold Creek.	Off Monroe Bay.	Church Point.	Total number of vessels.	Total number of men.	Remarks.
Feb. 2	12	8	1	5	....	3	5	7	....	3	3	....	....	....	2	49	275	1st, 4th, 5th, 8th, 12th, 13th, 14th, 15th, 22d, 24th, 25th, 26th, 27th, 28th no trips.
3	6	....	....	....	....	....	7	8	....	6	4	....	....	....	3	34	200	
6	5	....	....	5	....	5	3	1	....	3	2	....	....	....	1	25	150	
7	8	....	....	3	12	....	....	....	9	....	....	....	....	....	....	32	160	
9	22	3	1	1	....	6	2	6	....	3	1	....	....	....	1	46	265	
10	14	3	....	....	....	....	1	....	....	2	1	....	....	....	1	22	110	
11	12	....	....	5	3	....	....	....	....	....	....	....	....	....	....	20	120	
16	1	....	....	....	....	....	....	2	....	4	....	....	....	....	1	8	64	Very cold and rough.
17	....	....	....	....	....	....	....	....	3	....	....	5	3	2	....	13	78	
18	....	....	....	6	....	....	....	....	2	8	1	....	....	....	1	18	108	
19	12	3	1	5	....	....	....	3	....	2	3	....	....	....	4	33	190	
21	3	....	....	2	4	....	....	....	....	....	....	....	....	....	....	9	72	
23	10	....	....	....	....	....	....	....	....	....	....	6	4	....	....	20	120	Do.
Total	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	329	1,912	

Date.	Swan Point.	Cobb Bar.	Colonial Beach.	Lower Cedar Point.	Nomini Cliffs.	Wakefield.	Old Farm.	Lower Pope Creek.	Haywood Breaks.	Church Point.	Gum Bar.	Total number of vessels.	Total number of men.	Remarks.
Mar. 5	3	1	....	....	2	....	....	....	....	....	2	8	64	No trips made on the following days: 1st, 2d, 3d, 4th, 8th, 10th, and 15th.
6	8	....	1	2	....	....	....	....	....	....	....	11	80	
7	6	....	....	....	....	4	2	4	1	3	2	22	154	
9	3	....	....	8	....	....	....	....	....	....	1	12	84	
11	2	1	....	....	....	....	1	....	....	1	....	5	40	
12	3	....	....	12	....	....	....	....	....	....	5	20	160	
13	8	1	3	....	4	1	2	1	3	1	2	26	182	
14	10	2	4	....	....	1	5	2	....	....	6	30	240	
Total	....	....	....	....	....	....	....	....	....	....	....	134	1,004	

TABLE 43.

Month.	Daily average of number of vessels engaged in dredging.	Daily average of number of men engaged in dredging.	Monthly averages of B. coli in these waters (per c. c.).
1913.			
August	None.	None.	0.01
September	None.	None.	.03
October	None.	None.	.03
November	110	585	.03
December	65	300	.02
January	38	214	.10
February	25	147	.14
March	17	125	.04
April	None.	None.	.04
May	None.	None.	.07

STREAM FLOW AND TIDAL INFLUENCES IN THE LOWER RIVER.

In carrying out the studies of the natural purification of streams it was found essential to secure data concerning various hydrographic particulars. Request was therefore made to the United States Coast and Geodetic Survey for the assignment of a force to carry on hydrographic studies. The survey placed Mr. Homer P. Ritter in charge of this field work.

Inasmuch as that purification which takes place in the lower portion of the river is under present conditions of the most practical significance, the hydrographic studies were concentrated in that area to a large extent. Consecutive work of this character is extremely difficult of prosecution, since it is liable to interruption by storms, floating ice, etc., and is, at best, tedious and time consuming. This work is therefore incomplete as yet, although the data already collected have been of the greatest assistance to the investigators of the sanitary problems.

The limitations of the present report and the delay in receiving the records preclude the publishing herein of the carefully secured and valuable data as to temperatures at varying depths, salinometer readings, turbidity, and other matters of interest investigated by the Coast and Geodetic Survey. It is understood that the investigation of hydrographic conditions on the Potomac will be continued by the survey, and it is hoped a report giving all of the details will be published. Mr. Ritter has furnished complete field notes of the results of the work of his party, including all observations upon 59 float tests made during the course of the investigation. He has furnished carefully plotted charts showing the paths, times, direction, and velocity of the float during each observation; but, if reduced to the dimensions practicable in this report, these charts could not easily be interpreted, owing to the many intricate meanderings of the floats in the important tests. Charts N, O, P, Q, and R have therefore been prepared, showing the distance and direction traveled, velocity, and net gain of each test.

The many float observations which extended over only one or two tides are of value, chiefly because they offer an explanation of the varying numbers of *B. coli* found at different stations. The observations, which covered periods of several tides and often several days,

show the net gain downstream during such periods under the prevailing conditions of tide, wind, and stream flow.

Unfortunately such a small number of observations have been made in the extreme lower portion of the river that it is impossible to make, from the float data furnished, any accurate calculation as to the time which would be occupied by sewage in traveling from Washington to the Popes Creek or Lower Cedar Point cross sections under all conditions.

The observations of the float, started April 27 during the heavy freshet, and of the advance of the turbidity line during the same time, is of great interest in showing the minimum time occupied by suspended matter in traveling from the Washington sewer outlet to Stump Neck, under great and long-continued freshet conditions in the upper river. It is most unfortunate that the float was not allowed to continue under observation, for the probable minimum time interval could thus have been approximated. It must, however, be remembered that at Stump Neck and Possum Point the influence of the flood or increasing tide with its sea water becomes potent, and the total content of that section or prism of the river is so great that even great stream flows have a comparatively small displacement capacity. It is believed that under such unusual conditions as existed at that time some of the water from the upper river would probably reach the section about Popes Creek and below in a few days, but the results of the bacterial examinations of shellfish and water do not show that dangerous conditions existed.

The observations of floats have been numerous enough to show the approximate time, under ordinary conditions, from the upper river to Maryland Point; but so far they have not been such as to show the total time required by suspended matter in being transported from the Washington sewer outlets to the shellfish beds under conditions of greatest stream flow. The latter is the practical sanitary problem, and, for the present at least, dependence must be placed upon the results obtained from laboratory analyses of water and shellfish taken throughout the year. The results of such analyses show no pollution in the shellfish which could reasonably be attributed to sewage from the upper river, nor from Washington, and, in fact, as stated elsewhere, no samples of oysters from the Potomac River itself were found to be dangerously polluted from any source.

Mr. Ritter's report on the hydrographic studies carried on thus far follows as a separate section.

HYDROGRAPHIC DATA.

By Homer P. Ritter, *Assistant, United States Coast and Geodetic Survey.*

CURRENT WORK ON THE POTOMAC RIVER.

Instructions.—Instructions from the Superintendent of the Coast and Geodetic Survey, dated June 16, 1913, directed me to take charge of the current work on the Potomac River, requested by the United States Public Health Service, and after a consultation with the authorities of the United States Public Health Service as to the objects that the work is to subserve, to organize a party and proceed with the work. In accordance with the above I called at the office of the Surgeon General and was directed to confer with Dr. Hugh S. Cumming, as he was in immediate charge of the investigations being made by them.

Information requested.—On the 17th I called on Dr. Cumming at the Hygienic Laboratory and was informed that the data desired by them from the Coast and Geodetic Survey were such as would have a bearing on the question of "to what extent the tides affect and how far the currents carry the sewage from this vicinity toward the oyster beds in the lower Potomac and the amount of dilution the waters of the river undergo from the fresh-water streams or influx of salt water from Chesapeake Bay," etc.

Equipment.—The 40-foot Coast and Geodetic Survey launch *Inspector*, which was then undergoing repairs and being overhauled at Baltimore, Md., was assigned to aid in carrying on the work.

Pending the arrival of the launch preparations for the Potomac River work began by installing a self-registering tide gauge at Alexandria, Va. The tidal observations began on July 1, 1913. On July 31 the launch arrived from Baltimore, Md., and on August 4 the current observations were started and were continued at various times when weather conditions permitted until October 23, 1914.

Party.—From August, 1913, to April, 1914, the party consisted of myself and from five to six "hands." Subsequently to May, 1914, the personnel of the party was increased to nine "hands." From September to April a Coast and Geodetic Survey aid was assigned to the party—Mr. W. D. Sutcliffe, from September 12 to March 28 and again from April 17 to April 29; Mr. M. E. Levy from April 2 to April 16.

Floating plant.—In addition to the 40-foot gasoline launch *Inspector*, two 18-foot flat-bottom rowboats were used in getting about and following the current floats. During the continuous day and night float observations, which began in May, a small motor boat belonging to one of the "hands" was also used. The two launches furnished the sleeping and living accommodation during these series of observations.

Scope.—The current work had in view the determination, by means of floats, of the actual current paths in various parts of the river, especially with reference to the movement of the water in the vicinity of the Washington sewer outlet ($1\frac{1}{2}$ miles south of the junction of the Georgetown, Washington, and Anacostia Channels) and to ascertain the rate and extent of the probable downstream movement of the sewage discharge.

Method.—In general, the method pursued in making the float observations was to follow the float with a rowboat, in which were two observers with sextants and a boatman, the launch, manned by an engineer, steersman, and deck hand, being employed to convey the observers, boat, and float to the starting point and standing by until the close of the observations. When beginning a series of observations the float was set adrift, the time noted, and two sextant angles taken by the two observers in the boat to three fixed and located points on shore or located buoys in the river. At the same time the boatman took a sounding.

At frequent intervals the boat was rowed close to the float and its position again determined. These observations, together with the state of the weather, condition of the water's surface, direction and force of the wind, direction of current, etc., were recorded and constitute the field record. Whenever practicable the observations were started a short time before the beginning of an ebb or flood currrent and continued throughout that tide. At first all the float observations were made during daylight hours. Later on, at the end of the day's observations, the float was left to run unattended during the night, and if found still floating on the following morning the observations were continued. But as this method did not prove very satisfactory the party was increased in size, divided into three eight-hour shifts, and the float followed continuously day and night, until the observations had to be discontinued on account of stormy weather—generally not until the float and sometimes the boat had been blown on shore or into shallow water. Since May 11, 1914, continuous float observations lasting from two to five days were thus obtained.

During the night observations the float path was located by noting the time when passing buoys, wharves, lighthouses, beacons, and other located objects, estimating the distance out into the channel and taking soundings at the time. On account of the narrowness of the

channel, the numerous buoys, and other marks in the stretch of river so far surveyed, frequent positions of the float were obtained during the night.

Floats.—At the beginning the current observations were made with a current pole 15 feet long, weighted so as to float a foot and a half out of water. The diameter of this float was 3 inches, and it weighed 38 pounds.

From May 7, 1914, the float used was an exact copy of the float used in 1913 by the Metropolitan Sewerage Commission of New York, and, as described in their preliminary report of October, 1913, consisted of a piece of 4 by 4 inch timber, 6 feet long, around the upper end of which was built the float proper, a block of wood 12 by 12 by 24 inches. On the lower end of the stem were 4 vanes 21 inches by 18 inches, placed at right angles with one another and made of No. 14 gauge sheet iron.

A $\frac{3}{8}$-inch rod, for carrying a flag by day or lanterns by night, projected about $3\frac{1}{2}$ feet above the top of the float; it was supported at its middle point by a frame of four $\frac{1}{8}$ by 2 inch flat bars. At the top of this frame were placed two 3-inch rings, for convenience in catching the float when removing it from the water. This pattern of float was found to work admirably. When in the water the float was submerged, so that the top was about even with the surface of the water. The float weighs 145 pounds. From April 2 to May 7 the float used in the river south of the southern end of the Georgetown Channel was a piece of Georgia pine, 9 feet long, submerged 7 feet, with a 30-pound iron weight attached to the bottom, giving an additional foot under water. From January 6, 1914, to May 2, when taking the float observations between Chain Bridge and Aqueduct Bridge, a 4-foot pole float, submerged 3 feet, was used. This float was 3 inches in diameter.

Summary of current work and localities occupied.—From August 4, 1913, to October 23, 1914, 109 series of current observations, extending from a few hours to over five days each, were made, on 158 days. The number of miles traveled by the floats was 1,124; number of current path positions determined, 3,189.

The places from which the float observations were started at various times during the season were: Chain Bridge; Aqueduct Bridge; Georgetown sewer outlet; Georgetown Channel; Anacostia River; south end Anacostia River; Washington sewer outlet; Alexandria, Va.; Jones Point Light, Va.; Fort Foote, Md.; Riverview wharf, Md.; Marshall Hall, Md.; Indianhead, Md.; Possum Point, Va.; Maryland Point Lighthouse; Upper Cedar Point, Md.; Popes Creek, Md.; Upper Machodoc Creek to Colonial Beach.

Compilation of the data.—The method pursued in the reduction and compilation of the data obtained in the field consists in plotting,

on a Coast and Geodetic Survey chart, the actual path taken by the float during each series of observations, and compiling for each series a table giving a synopsis of the observations with reference to the direction and changes in direction of the tidal current, time run, and distance traveled, together with wind and weather conditions. Fifty-nine of the series of observations have been plotted and the 59 corresponding tables compiled.

OBSERVATIONS ON SPECIFIC GRAVITY, TEMPERATURE, TURBIDITY, ETC.

In addition to the current work, observations bearing on the physical condition of the river were taken at various times and places. They consisted of specific gravity determinations, water and air temperatures, color, turbidity, ice, wind, and weather conditions.

The 45 localities at which observations of the above kind were taken are distributed along the river from Chain Bridge to Point Lookout, where the Potomac empties into Chesapeake Bay. They were taken at various times between August 6, 1913, and December 31, 1914. Turbidity observations, which consisted principally in noting the color of the water, were made on 356 days and comprised 2,687 determinations. Specific gravity observations were made on 112 days and 2,485 observations taken. Temperatures of water and air, 280 days, with 3,207 water and 1,616 air determinations.

The specific gravity determinations were made with a field hydrometer, the observations being taken at 2 feet below the surface, mid-depth, and 2 feet from the bottom, and consisted of hydrometer readings, together with temperature of water at each depth and the temperature of the air, etc., at each station.

Whenever practicable, the stations were occupied in a series covering the river between Aqueduct Bridge and Alexandria on one day, followed the next day by a series extending from Alexandria to Indianhead, or vice versa. On and after June 16, 1914, the observations were extended as far as Point Lookout to the southward and Chain Bridge to the northward.

The localities at which observations on specific gravity, temperature, turbidity, etc., were made were as follows:

1. Chain Bridge.
2. Aqueduct Bridge.
3. Georgetown sewer outlet, District of Columbia.
4. Highway Bridge, Georgetown Channel.
5. South end Georgetown Channel, black buoy No. 1.
6. Benning Road Bridge.
7. Anacostia Bridge, Anacostia River.
8. Washington sewer outlet, District of Columbia.
9. Alexandria, Va. (Macalester wharf).

10. Fort Foote, Md.
11. Riverview, Md.
12. Fort Washington, Md.
13. Black buoy 45 C, Mount Vernon, Va.
14. Marshall Hall, Md.
15. Red buoy 56.
16. Black buoy 43, three-fourths mile northeast of Craney Island.
17. Indianhead, Md.
18. Black buoy 37, off Mattawoman Creek.
19. Stump Neck wharf.
20. Beacon white light red buoy No. 52.
21. Black buoy No. 33.
22. Liverpool Point.
23. Black buoy No. 31.
24. Red buoy No. 46.
25. Red buoy No. 42.
26. Beacon red buoy No. 36.
27. Maryland Point Lighthouse.
28. Red buoy No. 28.
29. Metomkin Point light.
30. Black buoy No. 19.
31. Upper Cedar Point Lighthouse.
32. Mathias Point Lighthouse.
33. Persimmon Point beacon red light.
34. Lower Cedar Point Lighthouse.
35. Black buoy No. 13.
36. Bluff Point light.
37. Colonial Beach (black buoy F).
38. Black and white buoy B.
39. Cobbs Point lighthouse (buoy No. 9a).
40. Blackistone Island (red nun buoy No. 4a).
41. Nomini wharf.
42. Ragged Point Lighthouse.
43. Piney Point Lighthouse.
44. Travis Point (beacon light buoy No. 5).
45. Point Lookout (red nun buoy No. 2).

TIDAL OBSERVATIONS.

Alexandria, Va.—A Coast and Geodetic Survey automatic tide gauge, which records a continuous record of the height of tide, was installed at Alexandria, Va., during the last week in June, 1913. Observations began on July 1 and are still underway. The recording apparatus and float well are located in the southwestern corner of the warehouse on the wharf just south of King Street.

In accordance with the practice of the survey, the zero of the gauge and auxiliary tide staff was connected by levels with three bench marks, to permit resetting in case of accident or reestablishing the gauge at some future time. The record was removed from the recording apparatus about once a month and forwarded to the Coast and Geodetic Survey Office at Washington.

Chain Bridge and Benning Road Bridge.—The stage of the Potomac River at Chain Bridge and that of the Anacostia at Benning Road Bridge were frequently determined by tide-staff readings made in connection with current work near those localities and at other times when an observer could be spared from the party for that purpose. Observations in this manner have been taken at Chain Bridge since December 26, 1913, and at Benning Road Bridge since January 16, 1914.

NOTES FROM THE FLOAT OBSERVATIONS.

CHAIN BRIDGE.

May 28, 1914, a float, started at Chain Bridge, after 31.35 hours reached a point 0.9 of a mile south of the sewer outlet, a distance of 10.34 miles—a rate of 0.29 of a mile an hour, or 6.96 miles a day. The observation for one complete cycle of tide, 12 hours, 24 minutes, shows an excess of 2.6 miles ebb.

August 10, 1914, 10.36 a. m.; a float started at the Chain Bridge and observed until August 15, 2.41 p. m., showed in 18 complete tides a net downstream gain of 10.8 miles in 97 hours, 29 minutes; 0.109 of a mile an hour, or 2.61 miles a day, having in the mean time traveled 39.2 miles during 57 hours, 20 minutes ebb tide, and 15.1 miles during 40 hours 9 minutes flood tide.

GEORGETOWN.

November 1: A float from Aqueduct Bridge showed ebb velocity of 0.55 mile an hour.

September 18: A float from Georgetown sewer showed ebb velocity of 0.18 mile an hour.

October 16: A float from Georgetown sewer showed ebb velocity of 0.27 mile an hour.

October —: A float from Georgetown sewer showed ebb velocity of 0.4 mile an hour.

September 3: A float started at the south end of Anacostia River reached Washington sewer outlet, a distance of 2.1 miles, in 5 hours 12 minutes—a rate of 0.4 mile an hour. The total ebb tide showing a distance of 2.3 miles, or 0.38 mile an hour.

November 5: A float in the mouth of Anacostia River showed a velocity of only 0.7 mile an hour.

WASHINGTON SEWER OUTLET.

Float observations in the vicinity of the Washington sewer outlet showed the following results:

August 20: In a complete ebb tide a float traveled from the Washington sewer outlet to Jones Point (2.9 miles) in 5 hours 30 minutes—an average time for the entire tide of 0.5 mile per hour.

August 25: In a complete flood tide a float traveled in 4 hours, 50 minutes, 1.8 miles, or an average of 0.37 mile an hour.

August 27: Complete flood tide, a float traveled 2.1 miles north of Washington sewer outlet and then turned back, 4 hours 59 minutes—0.4 mile an hour. Time of complete flood, 5 hours 22 minutes—0.5 mile an hour.

September 2: Complete ebb tide, 5 hours 40 minutes, traveled 4.7 miles—0.8 mile an hour.

Float passed Fort Foote, 4.3 miles from Washington sewer outlet, in 4 hours 2 minutes—1.1 miles an hour.

September 11: Three hours and fifty-five minutes of flood tide carried a float 1.9 miles north of the outlet.

September 13: Part of ebb tide, a float started at the outlet traveled 2.5 miles in 5 hours 1 minute—0.5 mile an hour.

It was noted that the current ran upstream about 1 hour on the Virginia side before turning on the Maryland side.

September 17: Float started abreast of the outlet passed Fort Foote in 4 hours 34 minutes—0.93 mile an hour. Entire tide, 6 hours 51 minutes—5.8 miles, or at a rate of 0.85 mile an hour.

September 23: A float started from an outlet showed, during 3 hours 48 minutes of flood, 1.5 miles, or 0.4 mile an hour; 3 hours 57 minutes of ebb, 2.0 miles or 0.5 mile an hour.

September 25: A complete flood tide, 6 hours 37 minutes carried a float 2.6 miles—0.4 mile an hour.

September 27: Float started abreast of sewer outlet showed velocity of 0.8 mile—2.2 miles (abreast Alexandria).

September 29: Float started abreast Washington sewer outlet on an ebb tide passed Fort Foote (4.3 miles) in 3 hours 32 minutes—1.2 miles an hour; the total time observed being 4 hours 49 minutes—4.8 miles, or 1 mile an hour.

October 1: Part of ebb tide approximated 1 mile an hour, Washington sewer outlet to Fort Foote, 4 hours 56 minutes—0.9 mile an hour.

October 2: Part of ebb tide, 5 hours, 4.1 miles—0.8 mile an hour.

October 6: Part of flood tide, 3 hours 45 minutes—2 miles, or 0.53 mile an hour.

October 11: A float started from Washington sewer outlet showed an ebb tide rate of 0.7 mile an hour, traveling 2.3 miles to abreast of Alexandria in 3 hours, 42 minutes.

October 17: One complete ebb tide carried a float from Washington sewer outlet down 6.5 miles in 6 hours 28 minutes—1 mile an hour—and, from the outlet, 4.3 miles, to Fort Foote in 3 hours 30 minutes, or 1.40 miles an hour.

October 30: Part of ebb tide carried float from Washington sewer outlet during 3 hours 26 minutes, 4.3 miles, to Fort Foote—1.3 miles an hour—and in 3 hours 48 minutes traveled 4.8 miles—1.3 miles an hour.

November 3: Part of ebb tide carried float in 2 hours 22 minutes 2 miles—0.8 mile an hour—and from the turn of tide to end—0.7 mile an hour.

April 6, 1914: Four hours eight minutes of flood tide carried float 1.9 miles, or at a mean velocity of 0.46 mile an hour.

April 7: A float started abreast the sewer outlet at the turn from ebb to flood, was left to float all night and found afloat in the channel about Macalaster Wharf, Alexandria, Va.

April 8, 1914: Left to drift all night was found aground south of Fort Foote 9 a. m. In 23 hours 48 minutes the float worked down the river 4.8 miles—0.2 mile an hour.

April 13: Started abreast of outlet, reached Fort Foote in 3.04: 1.4 miles an hour. Left to run all night, was found aground abreast of Fort Washington, 8.3 miles from outlet—a minimum velocity of 1.4 miles an hour.

April 16: Part of flood and part of ebb tide. A float started at Washington sewer outlet, during 2 hours 28 minutes of flood tide, traveled upstream 0.9 mile—0.36 mile an hour. Left adrift, was found abreast of Alexandria; 2 hours 42 minutes of ebb tide traveled 0.8 mile—velocity of 0.3 mile an hour.

April 17: Started abreast Washington sewer outlet at 9.20 April 17 and left to float all night. Found, 11.16 a. m. the following day, afloat a short distance below B buoy 43, 13.7 miles below Washington sewer outlet, traveling north.

One flood tide and one continuous 22 hours' ebb. Flood tide in 1 hour 45 minutes—0.2 mile, or 0.11 mile an hour. During the 22 hours from April 17 to 10 a. m. April 18 the float probably traveled to Glymont, 18.7 miles south of outlet before turning—0.85 mile an hour. The current turned north between Marshall Hall and buoy 56 at 10.17, April 18. As the current probably did not travel more than 0.4 mile north after 13 hours 57 minutes, the net result was about 15 miles from Washington sewer outlet; 26 hours 40 minutes, 15 miles—0.5 mile an hour.

April 22, 23, 24: A float was started April 22, 8.37 a m., from abreast the outlet and left to drift all night of April 22, and again left to drift all night of April 23, and found 10.39 a. m. April 24, aground abreast red buoy 56. In the stretch of river from 1.2 miles south of Fort Foote to 1.6 miles south of Marshall Hall (8.3 miles) the float traveled continuously, during two flood and two ebb tides, 25 hours 9 minutes, at the end of which time the float was 8.3 miles farther down the river, an excess of ebb over flood of 8.3 miles—0.33 mile an hour.

Float started at Washington sewer outlet, 8.37 a. m., reached Fort Foote in 3 hours 37 minutes—4.3 miles, or 1.2 miles per hour; end of ebb tide 5 hours 15 minutes, 5.5 miles, 1.52 p. m.—1.05 miles per hour.

Float started at Fort Washington April 23, 2 p. m., reached Marshall Hall, 3.9 miles, in 2 hours 48 minutes—1.4 miles an hour; end of ebb tide 5.2 miles, 5 hours 47 minutes—0.9 mile an hour.

April 27 to 28, 1914: There was a heavy freshet in the river, causing a rise of 9.5 feet at Chain Bridge. From April 27, 8.55 a. m., until April 30, 4.45 a. m., 68 hours, the current was constantly downstream at Alexandria. The following, therefore, showed conditions during a heavy stream flow: A float started abreast the Washington sewer outlet April 27, 8.45 a. m., at the beginning of ebb tide, reached Fort Foote (4.3 miles) in 3 hours 0.02 minutes; Fort Washington (8.3 miles) in 5 hours 0.09 minutes. Left alone to drift all night, the float was reported at Stump Neck (26 miles) at 6.30 a. m. April 28, or 21 hours 45 minutes after the start. From Washington sewer outlet to Fort Foote the current rate was 1.42 miles an hour. From Washington sewer outlet to Fort Washington the current rate was 1.61 miles an hour. From Washington sewer outlet to Stump Neck the current rate was 1.20 miles an hour. From Fort Foote to Fort Washington the current rate was 1.90 miles an hour. From Fort Washington to Stump Neck the current rate was 1.07 miles an hour.

April 27, 3 p. m., the front edge of a freshet of dark-red water from the Potomac River appeared abreast of Riverview, and at 1 p. m., April 28, appeared 0.3 mile below Glymont, the distance between the two points being 10.9 miles; the current, therefore, was about 1.12 miles.

May 11 to 13, at 8.53 a. m., the current just beginning ebb, a float was started abreast the outlet. At 9 o'clock p. m. the following day, May 12, it was lost in a southeast gale, and found at 10.30 a. m., May 13 ashore, abreast of Fort Hunt long wharf. During this time it passed Fort Foote three times and Fort Washington five times.

Started at the first of ebb, the float reached Fort Foote, 4.3 miles, in 3 hours 35 minutes; Fort Washington (8.3 miles from Washington sewer outlet) in 6.08 hours, and having traveled 9.1 miles in 7.15 hours (a rate of 1.26 miles an hour); 8 hours 39 minutes after the start it again passed Fort Washington with the flood tide, and in 11.43 hours passed Fort Foote. In 12 hours 39 minutes, having traveled 5.2 miles north, the tide again turned from north to south (flood to ebb) and passed Fort Foote in 13 hours after the start, making a net down gain of 4.3 miles in 13 hours, during which time the float had traveled 14.6 miles. After 16.03 it passed Fort Washington, and 19.22 Marshall Hall

(12.2 miles from Washington sewer outlet); 22.02 it passed Fort Washington on flood tide and 26.33 the same place on an ebb tide; 31.52 it was 0.5 mile south of Marshall Hall, excess of ebb tide 6.4 miles in 28 hours 58 minutes—0.22 per hour, 6.4 miles a day.

Ebb 7 hours 15 minutes, 9.1 miles; rate per hour, 1.26 miles.

Flood 5 hours 24 minutes, 5.2 miles; rate per hour, 0.97 mile.

Ebb 7 hours 31 minutes, 7.8 miles; rate per hour, 1.04 miles.

Flood 4 hours 44 minutes, 5.3 miles; rate per hour, 1.12 miles.

Ebb 6 hours 58 minutes, 6.3 miles; rate per hour, 0.90 mile.

May 14 to 15: A float was started at Washington sewer outlet about the beginning of ebb 10.40 a. m., and at 2.15 a. m., May 15, a squall put out the lights and the float was lost; found 3 hours later and put in channel.

Ebb for 8 hours 25 minutes, 8.4 miles; rate per hour, 1 mile.

Flood for 4 hours 40 minutes, 3.9 miles; rate per hour, 0.83 mile.

Excess of ebb, 4.5 miles in 13.05 hours—0.34 mile per hour or 8.2 per day. Float started at outlet, reached Fort Foote (4.3 miles) in 4 hours 38 minutes—rate, 0.93 mile. Fort Washington (8.3 miles), 7 hours 31 minutes—1.11 rate per hour. After reaching 0.2 mile south of Fort Washington a flood took it to 0.1 mile south of Fort Foote, and then ebb again 3.7 miles in 3.55—0.94 mile an hour.

May 18 to 22: At 9.19 a. m., May 18, a float was started abreast the Washington sewer outlet and observed night and day until May 22, 8.20 p. m., when a storm blew it ashore. During this 107 hours 1 minute the distance traveled by the float was 79.8 miles in 17 complete consecutive tides, 9 ebbs and 8 floods, during which the float passed the starting point 5 times. The southern limit of observation was 13.1 miles below Washington sewer outlet; the northern limit of observation was 1.7 miles above Washington sewer outlet. During the 8 tidal cycles there was an ebb excess of 12.3 miles in 98 hours 11 minutes—0.125 per hour or 3 miles per day in 73.5 miles traveled by the float.

ALEXANDRIA.

August 5, 1913: Float started abreast of Alexandria, Va., at the beginning of ebb tide; drifted 7.3 miles in 5 hours 30 minutes—1.3 miles an hour. Passed Fort Foote (3 miles) in 2 hours 40 minutes—1.13 miles per hour. Passed Fort Washington (7 miles) in 5 hours 10 minutes—1.35 miles per hour.

Fort Foote to Macalester wharf, Alexandria, 2.4 miles, 1.30 hours—1.6 miles per hour. Fort Washington to Macalester wharf, Alexandria, 6.4 miles, 4 hours—1.6 miles per hour.

August 12: In a complete flood tide from abreast of Alexandria the float traveled 3.2 miles in 5 hours 45 minutes—0.56 mile an hour. Reached sewer outlet, 1.9 miles, in 2 hours 37 minutes, or 0.73 mile an hour.

September 22: A float started as above from abreast Alexandria wharf during part of flood and part of ebb tide; flood, 3 hours 14 minutes—0.5 mile, or 0.16 mile an hour; ebb, 2 hours 27 minutes—1 mile, or 0.41 mile an hour.

September 24: One complete flood-tide float from same start drifted in 5 hours 11 minutes 2 miles—0.38 mile per hour.

October 15: A float from same start during part of ebb tide, 4 hours 35 minutes, 4.2 miles—0.75 mile per hour. Passed Fort Foote, 2.4 miles, in 2 hours 36 minutes—0.9 mile per hour.

October 29, 1913: A float started 8.21 a. m. abreast Macalester wharf, Alexandria, Va., during part of ebb tide, drifted 8.7 miles in 6 hours 8 minutes—1.42 miles per hour. Float passed Fort Foote wharf 2.4 miles in 1 hour 19 minutes—1.85 miles an hour. Float passed Fort Washington, 6.4 miles, in 3 hours 30 minutes—1.83 miles an hour.

November 6, 1913: A float started for one complete flood tide from same place, 5 hours 21 minutes, 2.6 miles—0.49 mile per hour. Float passed Washington sewer outlet, 2 miles, in 3 hours 6 minutes—0.64 mile per hour.

JONES POINT LIGHT.

September 26: Floats started abreast Jones Point Light, Va. One complete flood tide the rate averages 0.7 mile; on ebb, 2 hours 20 minutes, drifted 1.3 miles, 0.1 mile north of Fort Foote—0.56; on flood, 5 hours 30 minutes, drifted 3.8 miles, 0.4 mile south of sewer outlet—0.7.

October 9, 1913: One complete flood tide, 5 hours 11 minutes, 3 miles—0.58 mile an hour. Starting at Jones Point Light, turns from ebb to flood, 0.7 mile north of Fort Foote; turns from flood to ebb 0.6 mile south of Washington sewer outlet.

FORT FOOTE, MD.

September 10, 1913: A float started 300 meters south of Riverview Wharf on flood tide, traveled 3.7 miles in 5 hours 12 minutes—0.71 mile an hour. Passed Fort Washington, 32 miles, in 5 hours—0.64 mile an hour.

October 7: Part of flood tide, float started abreast of wharf, flood 5 hours 6 minutes, 2.7 miles—0.53 miles per hour; passed MacAlester Wharf, 2.4 miles, in 3 hours 34 minutes—0.64 mile an hour.

MARSHALL HALL.

June 2, 1914: A float was started 12.57, June 2, abreast the wharf and observed until 3 a. m., June 4, when it was lost in a storm at night and found, 9.30 a. m., 100 feet southwest of lantern off Fort Washington. During this 38 hours and 3 minutes of continuous observation the float traveled 30.1 miles.

Southern limits of observations south of Marshall Hall, 5 miles. End of observations north of Marshall Hall, 3.3 miles. In the two tidal cycles observed there was an excess of flood—0.2 mile in 25 hours 32 minutes; the two flood tides totaling 10.1 miles and the ebbs 9.9 miles. Comparing the last flood and ebb, there was an excess flood in 24 hours 30 minutes of 2.5 miles—0.1 mile an hour.

June 8, 10.41 a. m.: A float started at ebb tide remained under observation until 4.10 a. m., June 9, when it was lost in a northeast gale abreast of black buoy 45, and found, June 13, 500 yards below Gunston Wharf, on the south side of Pohick Creek. The float starting from Marshall Hall went south 4.5 miles, then back north 5.4 miles (0.9 mile north of Marshall Hall), then south 5.7 miles (or 4.8 south of Marshall Hall)—a net gain south (ebb) of 0.3 mile in 16 hours 4 minutes—0.0186 per hour, or 0.446 per day.

June 9, 1914: At 3.35 p. m., on ebb tide, a float was started abreast of Marshall Hall Wharf and continued under observation until 1,20 p. m., June 13,, a period of 93 hours and 45 minutes, during which there were 15 consecutive tides—8 ebbs and 7 floods—in which period the float traveled a total distance of 88.4 miles—an average rate of 0.93 mile an hour. The southern limit of observations was 5.7 miles and the northern limit of observations was 8.5 miles. During the 86 hours 10 minutes of the 7 tidal cycles the float traveled 83.8 miles—0.97 mile an hour. There was a down gain (:. e., excess of ebb) during the 86 hours 10 minutes of 5.4 miles—down gain 1,5 miles in 24 hours.

June 22 to 27, 1914: A float was started abreast of Marshall Hall at 12.15 p. m. and continuously observed until June 27, 11.55 a. m. (4 days 23 hours 40 minutes), 119 hours 40 minutes, during which period it traveled 100 miles—0.835 mile an hour. There were 10 complete and 2 partial ebb tides and 9 full flood tides. In 18 consecutive tides (9 cycles) there was a down-stream gain

(i. e., excess of ebb) of 5.7 miles in 110 hours 7 minutes, or 0.0518 mile per hour—1.24 miles per day. Flood, 53 hours 45 minutes, 43.7 miles—0.81 mile per hour, or 1.94 miles per day. Ebb, 56 hours 32 minutes, 49.4 miles—0.87 mile per hour, or 2.08 miles per day. The extreme limit north of Marshall Hall reached was 5 miles (1 mile north of Fort Washington); the extreme southern limit was 5.7 miles (0.5 mile north of Glymont). The total distance gained south of Marshall Hall was 5.3 miles. Including the start, the float passed Marshall Hall 17 times.

INDIANHEAD, MD.

July 20, 1914: A float was started abreast of Indianhead Wharf at 12.35 p. m. and observed until 11.10 p. m., June 23, 1914, when a storm ended the observation. During this period there were 13 consecutive tides, 7 floods and 6 ebbs. The southern limit below Indianhead was 1.7 miles. The northern limit above Indianhead was 6.1 miles. During 80 hours 16 minutes the float traveled 53 miles, or at a rate of 0.66 mile an hour, or 8 miles per day. Of the 6 complete cycles, flood for 37 hours 30 minutes—24.7 miles, or 0.66 mile per hour; and ebb for 36 hours 54 minutes—24.7 miles, or 0.67 mile per hour. There was a downstream excess of 0.95 mile in 74 hours and 24 minutes.

July 24, 1914: A float was started at 7.32 a. m. and observed until 11.43 a. m., when a storm interfered with the observations. During a complete ebb tide for 5 hours 45 minutes there was a down progress of 5.2 miles—0.92 mile an hour.

POSSUM POINT.

August 27, 1914: A float was started at 5.24 p. m. abreast of Possum Point and observed until 9.18 a. m., August 29, a period of 39 hours 54 minutes, during which the float traveled 31.2 miles. During the 6 consecutive tides (3 floods, 3 ebbs) the southern limit of observations was 1.6 miles; northern limit of observations was 4.2 miles. Over the period of 38 hours 12 minutes the float traveled 30.6 miles, with a downstream gain of 1.4 miles—0.0366 per hour, or 0.8784 mile per day.

October 19 to 23: A float was started, 1.22 p. m., abreast of Possum Point and continued under observation until October 23, 8.05, when the illness of the observer ended the observations. During this period of 102 hours 43 minutes the float traveled 88.1 miles. There were 16 consecutive tides, 8 floods and 8 ebbs, covering flood 48 hours 53 minutes, 41.1 miles—0.84 mile an hour. Ebb 49 hours 53 minutes, 44.3 miles—0.89 mile an hour. There was a downstream gain of 6.1 miles in the 98 hours 46 minutes—0.061 mile per hour, or 1.464 miles per day. The southern limit of observations, 9.5 miles from start to end. The northern limit of observations, 4 miles from start to end.

MARYLAND POINT LIGHTHOUSE.

September 11, 1914: A float was started abreast this point at 8.34 a. m. and observed until 12.21 p. m. September 12, 1914. During this period of 27 hours 47 minutes the float traveled 24.5 miles. There were 4 consecutive tides, during which 2 floods, 12 hours 13 minutes, traveled 9.7 miles—0.8 mile per hour; 2 ebbs, 12 hours 45 minutes, traveled 13.4 miles—1.05 miles per hour. There was a downstream (i. e., ebb) excess of 3.7 miles in the 25 hours 18 minutes—rate of 0.146 mile per hour, or 3.504 miles per day. Southern limits of observations, 7 miles from starting point; northern limits of observations, 1 mile from starting point.

UPPER CEDAR POINT, MD.

September 22, 1914: A float was started abreast the lighthouse at the above point at 1.41 p. m. and continued under observation until 4 p. m. September 24, when a storm stopped the work. During this period of 50 hours 19 minutes the float traveled 55.6 miles. The northern limit of observation was 7.2 miles and the southern limit of observation was 4 miles from upper Cedar Point. During the observations, including start, the float passed the upper Cedar Point light nine times. There were eight consecutive tides (four floods and four ebbs). Floods 25 hours 3 minutes, float traveled 25.8 miles—1.03 miles per hour. Ebbs 24 hours 4 minutes, float traveled 29.1 miles—1.21 miles per hour. Downstream excess over 4 tides, 49 hours 7 minutes, of 3.3 miles—0.067 mile an hour, or 1.608 miles per day.

POPES CREEK, MD.

September 15, 1914: A float was started abreast this wharf at 12.02 p. m. and observed until September 16, 4.01 p. m., when the sea became too rough to continue. During this period of 27 hours 59 minutes the float traveled 13.8 miles. During 24 hours 56 minutes, covering 4 consecutive tides, the float traveled during flood for 10 hours 14 minutes 3.9 miles—0.38 mile per hour; ebb for 14 hours 42 minutes 9.6 miles—0.65 mile per hour. Plotting shows a downstream gain of 6 miles in the 24 hours 56 minutes—0.241 mile per hour, or 5.784 miles per day.

UPPER MACHODOC TO COLONIAL BEACH.

September 17, 1914: A float was started September 17, 8.46 a. m., abreast of can buoy 13 and observed until September 18, 7.22 p. m. During this period of 34 hours 36 minutes the float traveled 15.8 miles, the southern limit of observation being 7.2 miles and the northern limit being 0 mile from the starting point. During 4 consecutive tides, covering 25 hours 17 minutes, there were—flood, 9 hours 7 minutes, 2.5 miles; ebbs, 16 hours 10 minutes, 9.3 miles. There was a downstream excess of 7.2 miles in 25 hours 17 minutes—0.284 mile per hour, or 6.81 per day.

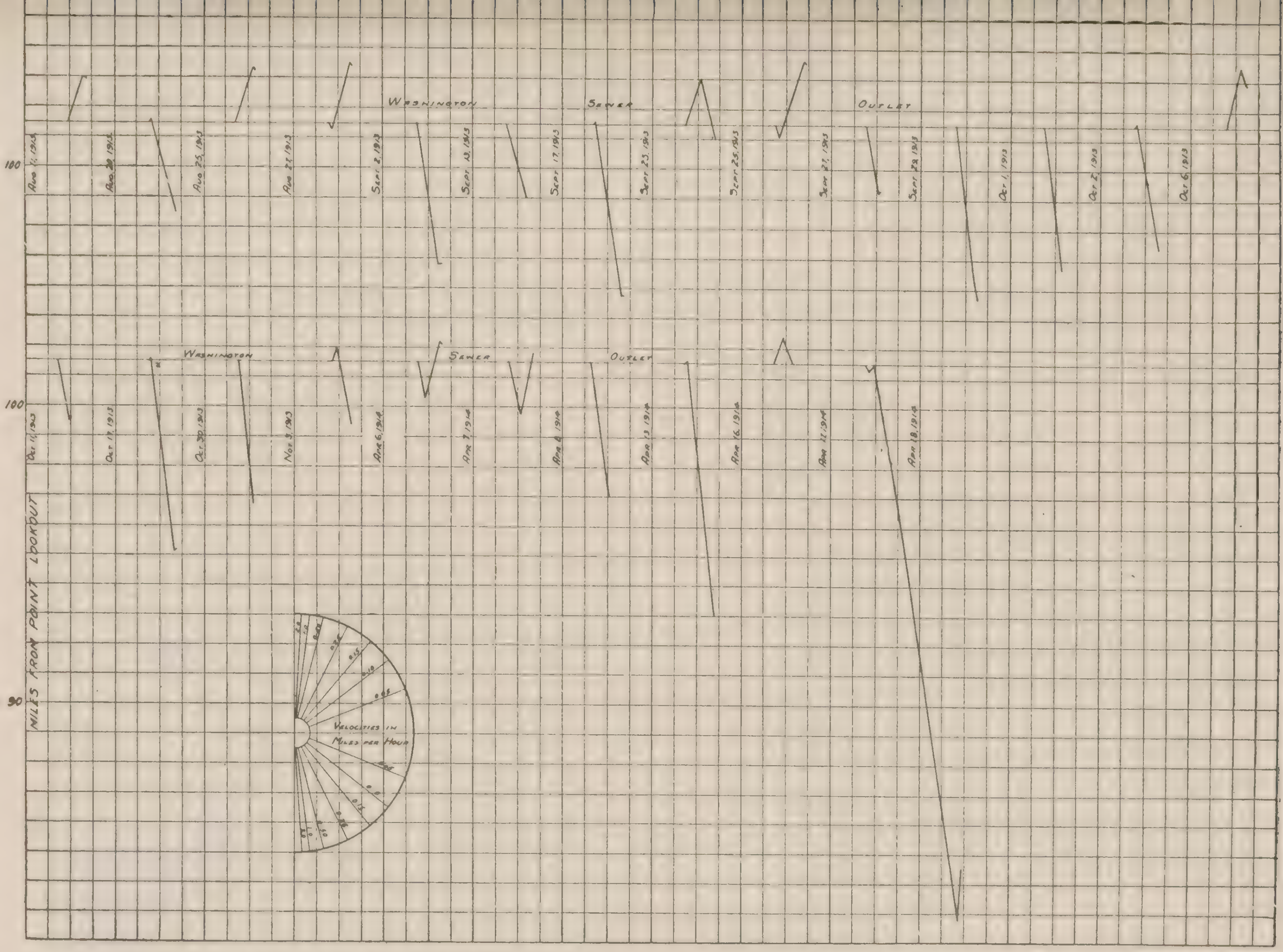

CHART N.—THE DISTANCES TRAVELED, VELOCITIES AND NET GAIN OF FLOATS STARTED AT THE WASHINGTON SEWER OUTLET AND OBSERVED BY THE U. S. COAST AND GEODETIC SURVEY.

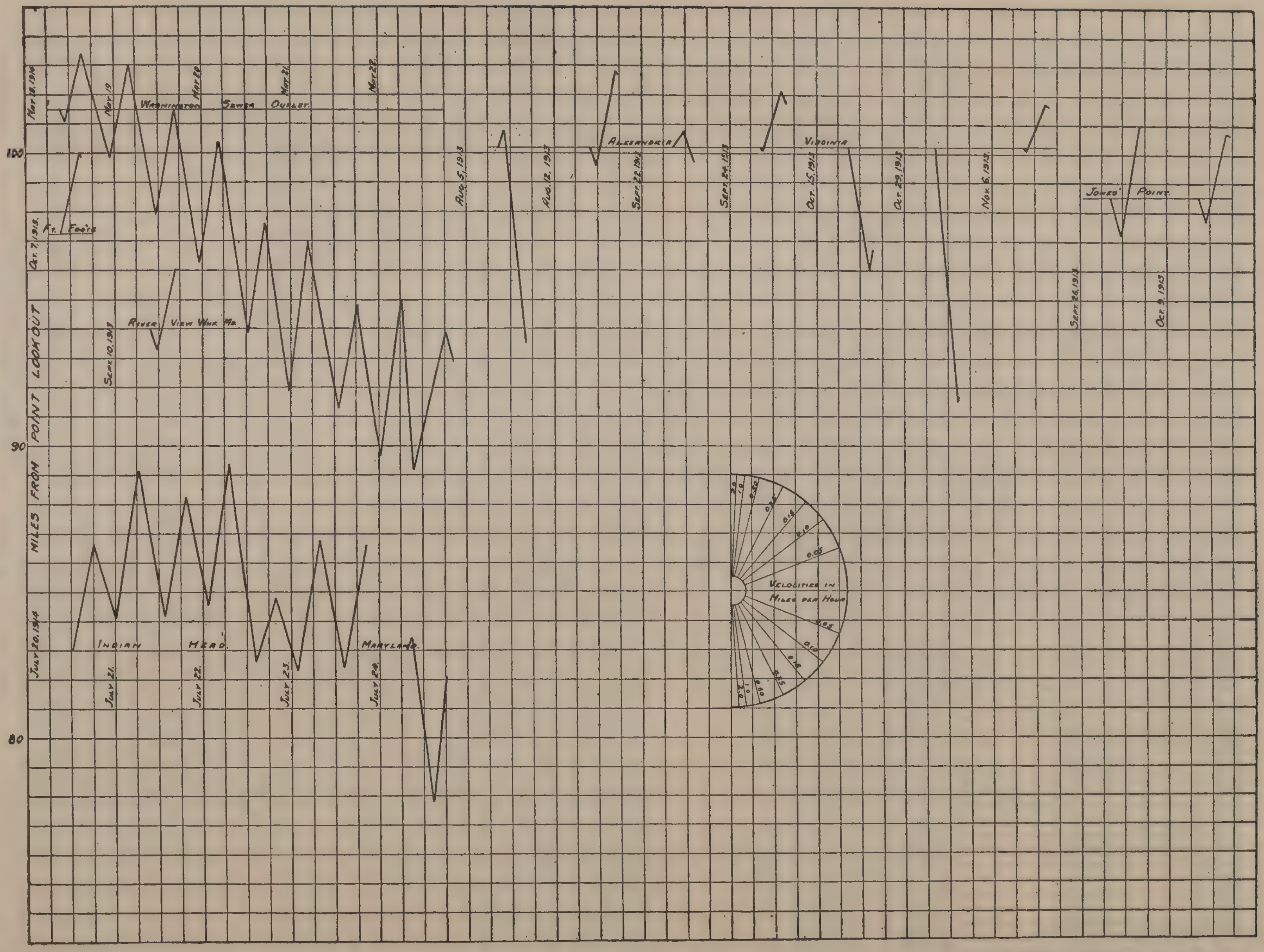

CHART Q.—THE RESULTS OF OBSERVATIONS BY THE COAST AND GEODETIC SURVEY UPON FLOATS

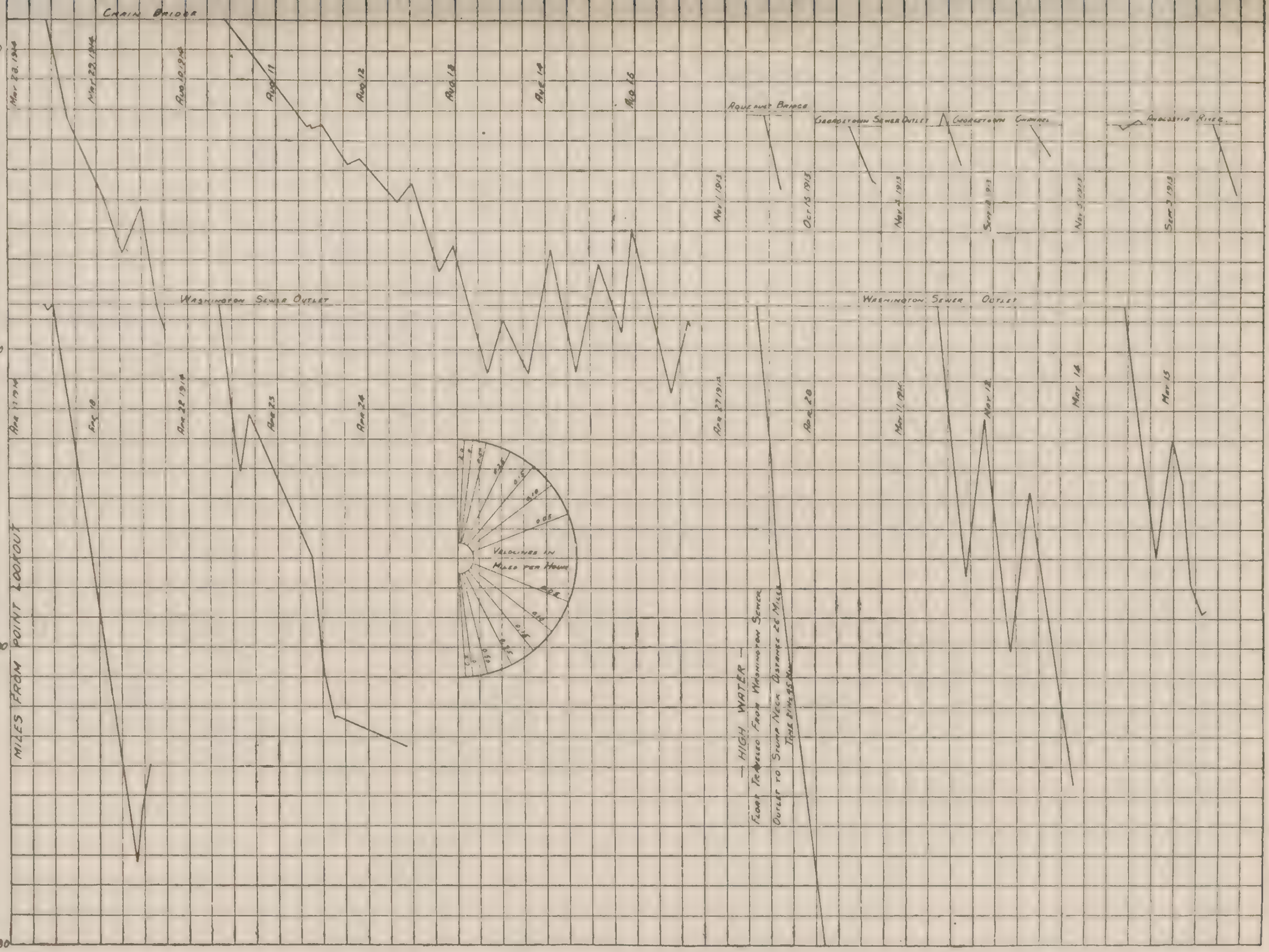

CHART P.—THE RESULT OF OBSERVATIONS BY THE COAST AND GEODETIC SURVEY UPON FLOATS STARTED AT CHAIN BRIDGE, AQUEDUCT BRIDGE, GEORGETOWN CHANNEL, GEORGETOWN SEWER, ANACOSTIA RIVER, AND WASHINGTON SEWER OUTLET, WITH TOTAL DISTANCES TRAVELED, VELOCITIES, AND NET GAIN.

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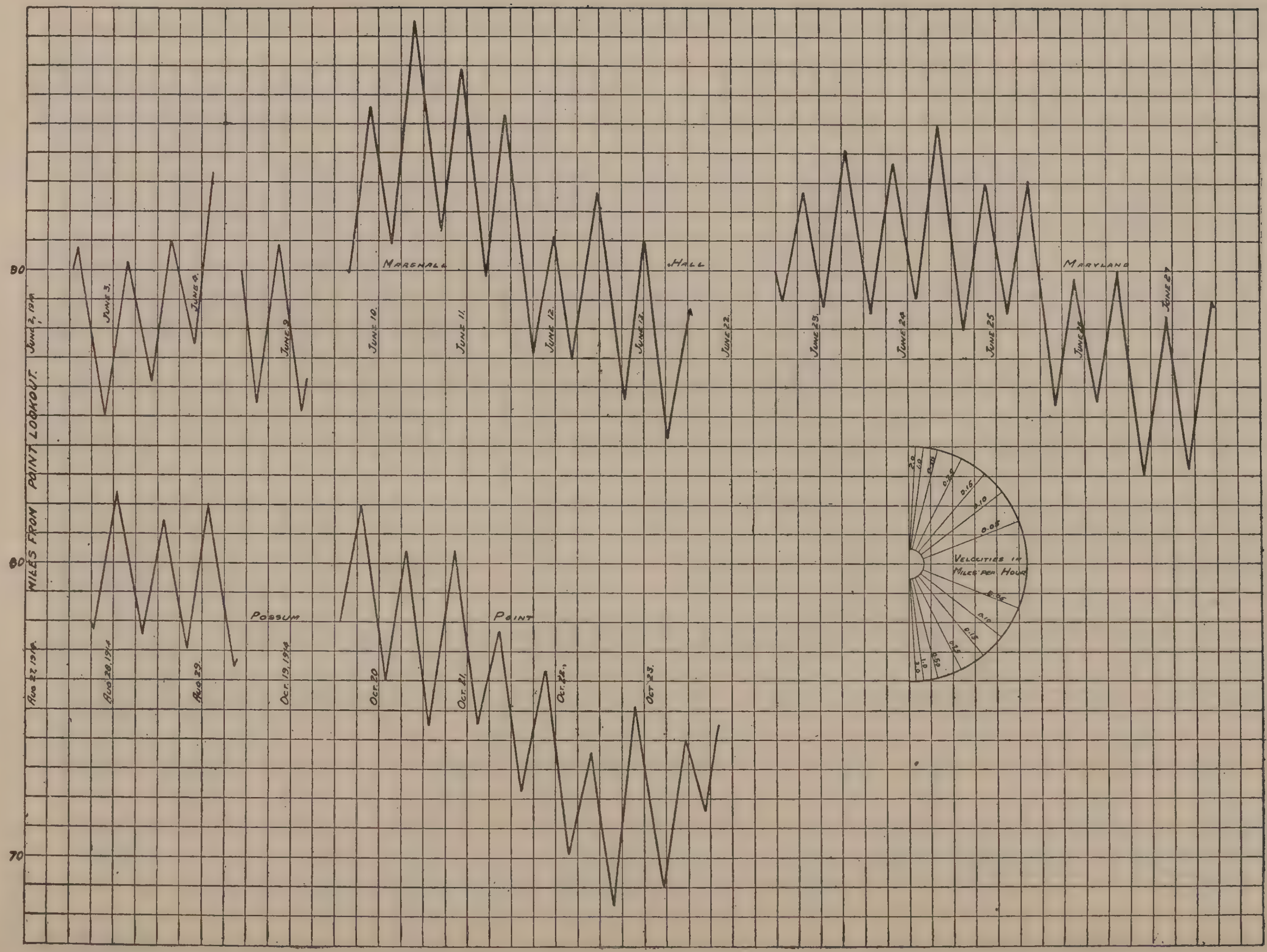

CHART Q.—THE RESULT OF OBSERVATIONS MADE BY THE COAST AND GEODETIC SURVEY UPON FLOATS

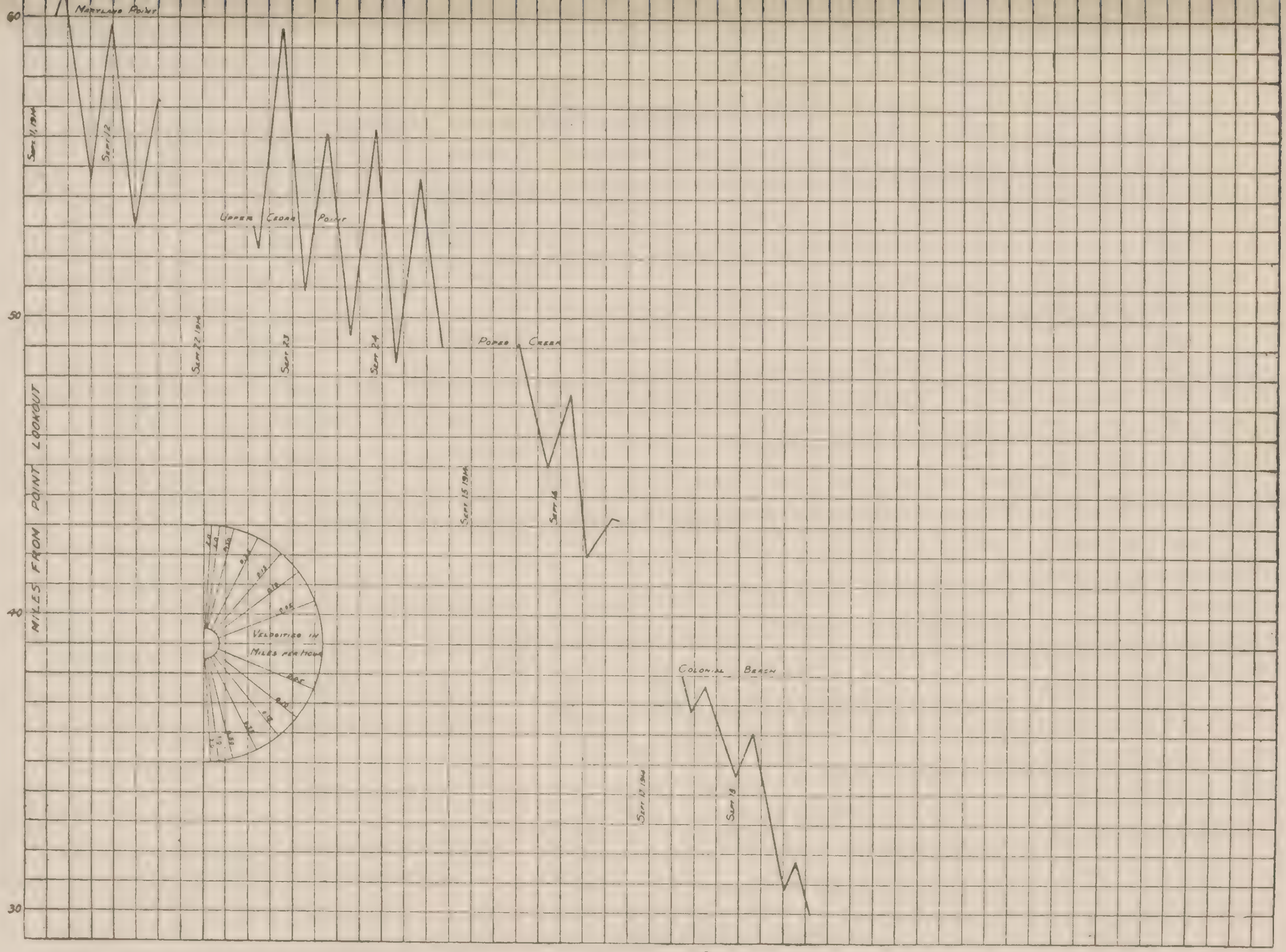

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CHART R.—THE RESULT OF OBSERVATIONS MADE BY THE COAST AND GEODETIC SURVEY UPON FLOATS STARTED AT MARYLAND POINT, UPPER CEDAR POINT, POPES CREEK, AND COLONIAL BEACH, WITH TOTAL DISTANCES TRAVELED, VELOCITIES, AND NET GAIN.

GENERAL DISCUSSION OF POTOMAC RIVER BY SECTIONS.

ABOVE GREAT FALLS.

North Branch.—The North Branch of the Potomac River, above Piedmont, W. Va., and Western Port, Md., drains a mountainous and heavily timbered country. The principal industries are mining and lumbering, and there is very little direct pollution except from the few privies along the stream. There is, however, a potential danger of infection from the use of this water because of its extremely rapid run-off. From Piedmont to Cumberland, the character of the river is considerably altered by the addition of large amounts of acid iron wastes entering through Georges Creek at Western Port and through Wills Creek at Cumberland. These streams traverse coal-mining regions and have a considerable population along their courses, Georges Creek being especially important in this respect. A considerable amount of trades wastes enters the two streams, together with crude sewage from the many towns. The effect of this sewage upon the stream, however, is remarkably reduced by the above-mentioned wastes, which act upon one another and upon the sewage in such a manner as to decrease considerably the bacterial content of the water. This action has been much more fully described in the report on the Cumberland and Piedmont region.

From Cumberland and Green Spring to the mouth of the South Branch of the Potomac there is very little direct pollution. The most important tributaries in this stretch of the river are Parsons Creek, on the south, and Evitts Creek, on the north. The watersheds of these streams are relatively uninhabited, being, for the most part, rough and mountainous, although there is more or less land suitable for agricultural pursuits along the valleys of the South Branch.

South Branch.—Two small towns and two tanneries discharge their effluents into this stream. Though the run-off from its watershed is quite rapid, the physical condition of the water where it joins the North Branch is relatively good, since the area is heavily timbered. The water from the South Branch is strikingly clear and sparkling when compared with that of the North Branch.

From Green Spring to Harpers Ferry.—From Green Spring, W. Va., to Williamsport, Md., the river flows through a tortuous channel, receiving drainage from a comparatively uninhabited region. Hence, from neither the north nor the south does direct pollution of any importance reach the river in this section.

At Williamsport, Md., Conococheague Creek enters from the north. This stream drains a comparatively heavily populated agricultural and industrial region. On the stream and its tributaries are numerous large towns, most of which contribute pollution in the way of sewage and trades wastes. Many towns, however, along the stream dispose of their wastes by running them into crevices in the limestone, which underlies this whole area. This same practice obtains in the area drained by Antietam Creek, which has an area similar in all respects to that drained by the Conococheague. Between the entrances of these two streams the Opequon enters from the south. This stream drains an agricultural region and also receives the wastes from the towns of Martinsburg, W. Va., and Winchester, Va., which are comparatively large manufacturing communities.

Harpers Ferry.—At Harpers Ferry the Shenandoah River joins the Potomac. The Shenandoah is by far the largest tributary of the river and, as a matter of fact, has normally a larger flow than the Potomac above Harpers Ferry. The headwaters of the Shenandoah drain a wooded, mountainous country containing very few towns. Along the valleys of the river, however, are numerous towns, almost all of which discharge into it sewage and trades wastes. These valleys also constitute the largest agricultural areas in the watershed. As a result the river always carries a high turbidity after a rain. This turbidity can be traced downstream from the confluence of the Shenandoah with the Potomac for a considerable distance, as it tends to hug the south bank. Samples collected at Harpers Ferry showed practically no difference in bacterial content between Harpers Ferry and Great Falls. The only other tributary of importance is the Monocacy River, which drains a considerable agricultural area, lying mostly in Maryland. In this watershed are numerous towns, almost all of which contribute more or less direct sewage pollution. The use of this land for agricultural purposes also makes the Monocacy a very turbid stream after rains. The drainage area of Goose Creek, which enters the Potomac from the south, has a comparatively small population and receives very little direct pollution.

Great Falls.—Great Falls is the last station on the upper river. It therefore shows the net amount of pollution from the upper river to this point, and as the location of the intake for the Washington water supply it has been extensively studied. The results show that the water there is generally of fairly good quality, but is subject to wide fluctuations after rains, and during the spring floods becomes very bad. No direct pollution enters for 19 miles above Great Falls, and the most characteristic features are the abrupt changes in quality. The bacteriological findings at Dalecarlia Inlet do not show these sudden changes quite as strikingly as would samples from the falls themselves.

Because of the prevalence of typhoid fever in the watershed, the rapid run-off of the river and its tributaries, and the consequent danger therefrom the raw water from the Potomac River at Great Falls is unsafe for use.

Since the foci of infection are scattered and largely rural, the treatment of the sewage of towns on the watershed would not entirely remove the danger of infection. There are, however, few places on the watershed where safe river water can not be secured by reasonable treatment.

BELOW GREAT FALLS.

The Potomac below the falls becomes broad, changes more slowly, and there are few interfering factors below the sewer outfalls of Washington and Alexandria; hence the conditions are favorable for laboratory investigation, and the work was concentrated upon this area. These results have been studied and developed and the data presented herein as to the conditions of "self-purification."

The section from Little Falls to Fort Foote is considered as the area of pollution, because the sewage and wastes from Washington, Georgetown, Alexandria, and the suburbs enter the river within that section.

Three Sisters.—Three Sisters is the highest station which could be reached by boat. It is nearly at the head of tidewater, and 10 miles below Great Falls. Some little pollution enters between these points, as is shown by the analyses, but there is very little. The tide rises and falls in this area, but, owing to the narrow channel, the consequent change in level is made up by the stream flow. The currents are seldom reversed, and, as the float tests show, "flood tide" consists in times of lowest stream flow, in a brief upward drift; while, in ordinary conditions, there is simply a retardation of the current.

From Three Sisters to Anacostia River.—The section of the river from Three Sisters to the junction of the main or Georgetown Channel with Anacostia River and Washington Channel comprises that portion of the river proper adjoining Washington and Georgetown. In addition to the pollution received above Three Sisters there is the direct sewage discharge of 7,000 persons, the drainage from Rock Creek and the Chesapeake & Ohio Canal, the discharge of a small city sewer, and effluents from numerous industrial plants, including several large breweries and a gas plant. Much of this pollution, however, will be carried to the city pumping station when the new interceptor is completed.

Float observations show that even during periods of lowest stream flow there is little real upward movement of water into this region during flood tides, upward drifts of floats at Giesboro Point diverg-

ing into Anacostia and Washington Channels, where no stream flow exists.

The natural bed and channel of the section have been narrowed by engineering works, such as filling of the flats; except during freshets, the effect of flood tides therefore is merely to act as a dam to back up the water, and create a more or less stagnant condition, affected, on the one hand, by stream flow from above and, on the other, by the pollution received.

Reference to the charts showing float observations in this area will show the variations in current rate. May 28 the float traveled from Chain Bridge to a point 0.9 of a mile south of the sewer outlet in 31.35 hours—a velocity of 0.339 mile per hour. On November 1 the ebb velocity was 0.55 mile an hour, while in August, during low stream flow, a float required 97 hours and 29 minutes to make approximately the same distance—a rate of 0.109 mile per hour. It is an important fact that these periods of low stream flow and stagnation occur during the summer months.

Bacterial results obtained at four stations in this area give *B. coli* counts of more than 100 per c. c., or approximately five times as many as are found at Three Sisters. Such results show pollution which render this section unsafe and unsuitable for river bathing, and it should be noted that the upper intake of the Tidal Basin receives its flow from this region, and thus connects it with Washington Channel.

Washington Channel and Anacostia River constitute an important stagnant area, affected, especially the former, chiefly by tides. Except for the canal and coal shipping at Georgetown, all of the shipping of Washington is received in Washington Channel and at the navy yard on Anacostia River.

Float observations show that flood-tide movements are diverted by the stream flow in the main or Georgetown Channel into this area. Since the Washington sewer outlets are only 2 miles below this point, and storm water and other sewers empty directly into this section, a large amount of sewage from both sources enters this region. As a consequence, during periods of small stream flow this area is heavily polluted and the bottom is foul. The records show more than 500 *B. coli* per c. c. during August, and other gas-forming organisms are present in much greater numbers. Such conditions are present oftenest during the hot months, and the bubbling, the oxygen determinations, and the odors, as well as the bacteria, indicate a condition of putrefactive changes consequent upon excessive pollution.

When the plans of the District engineer are carried into effect, no sanitary sewage will, it is stated, enter this region directly. The conditions now sometimes encountered from the sewage pumping sta-

tion to Giesboro Point should therefore disappear. It is probably true that much of the offensiveness of this area is due to the storm-water discharge, with its content of horse manure, etc.

Giesboro Point is only 1½ miles above the sewer outlets. It is about at the junction of the main channel, Anacostia and Washington Channels, and it is practically the cross section where the meeting of the upward flood currents and downward river flow results in a damming and retardation, rather than an upward flow. Hence the condition of the water at this point varies considerably, and, depending upon the stage of tide and flow of the river, may be very bad or better than sections within the reach of an ebb tide. Consequently during summer, when the stream flow is small, the water of this cross section is consistently the worst in the river; during the winter months, however, the flow is sufficient to outrun the flood-tide current, and the water here is greatly improved.

Washington sewage outlet.—About 1½ miles below Giesboro Point the sewage of Washington City is discharged from outlets on either side of the main channel at a depth of 25 to 30 feet, and the underrun of the polluted water is very marked, as is shown on the charts giving the results of analyses of surface and deep samples. The river in this vicinity was very carefully observed during the summer months, when evidences of excessive pollution and consequent nuisance would most probably be present.

The visible effect of the sewage is not very objectionable. At times a moderate amount of sleek is observable for a considerable distance in the direction of tidal flow, and matches, small bits of soap, paper, and other material may be seen floating in the sleek. At no time could the conditions be considered offensive or to constitute a nuisance; ordinarily the outlet discharges are not even evident. Even during hot weather the odor is very slight, and a disagreeable odor, at times noticeable in the vicinity, was greatest when the wind came from the Virginia shore, where a soap factory is located.

During the late summer months, when the high temperature of the water and the low stream flow from the upper river were coincident, and when, in consequence, the dilution was least and the danger of deficient oxidation with resultant nuisance was greatest, as many as 76 dissolved oxygen determinations were made daily upon fresh and incubated samples. The results show that for many years to come the river will have ample oxygen to care for the sewage from the estimated increased population of the vicinity.

A study of the float observations in the areas from Giesboro Point to Fort Foote or the stations immediately below shows clearly how slowly the water leaves this area of pollution; and if the study be confined to the stream and tidal flow alone, the bacterial and oxygen

conditions appear inexplicable. When a broader study of the area is made, however, the difficulty is removed. In the section on plankton studies it is shown that the broad areas of flats constitute veritable natural sewage-disposal plants in which large quantities of sewage are speedily broken down and from which come biologically active agents and an enormous output of oxygen, the approximate quantity of which has been calculated by Prof. Phelps and which is contained in the chapter on Plankton Studies. These factors exert a potent influence in the purification of the river, both in the "area of pollution" and in the lower sections of the river where such purification is completed.

The float observations as well as the bacterial results show that, starting even at the beginning of an ebb tide, under ordinary conditions, material from the sewer outlet does not reach far below the Fort Foote cross section and, in extraordinary freshets, not much below Fort Washington.

The pollution introduced into the river above is thoroughly diffused when it reaches this section, and little pollution of consequence enters below; hence this part of the river is considered the "area of pollution," and the section from there to Maryland Point the "area of purification."

Fort Foote.—The various float observations in this region, from Giesboro Point to Whitestone Point especially, show that in discussing distances in miles due consideration must be observed for the variations of distance in time consequent upon different rates of stream flow. From Whitestone Point down, however, the large volume of the river below equalizes the minor fluctuations noticed above. From this point the effect of stream flow is of less importance, and times can be reliably calculated in which the water will progress. Owing to the balance of effects, the average condition of the water at Fort Foote throughout the year is remarkably constant. In the summer, when pollution in the river is more concentrated, the time elapsed in which the sewage reaches this point is enough to allow for considerable purification. In the winter, when the dilution is greatest, it is not so affected, and the increased pollution coming from the upper river makes up for the difference.

Although the bacteriological results at Fort Foote are fairly constant, those below vary enormously from month to month according to the stream flow. At Fort Washington during the summer, when the calculated flow is small and when the floats show that it takes considerable time for the water to get from Fort Foote to Fort Washington, the purification accomplished in this region is very great. At these times the water contains fewer intestinal organisms than at Great Falls, in spite of the fact that it has received the sewage from 350,000 people. In the winter, when the stream flow is large and the

time of purification small, the extent of purification diminishes almost to nothing. There are very extensive flats opposite and above Fort Washington, which account for the rapid oxidation of the organic matter in the water when the conditions are worst, and so the bulk of the organic matter is either oxidized or settles out.

Mount Vernon and Marshall Hall.—The analyses at Mount Vernon and Marshall Hall also show some purification over those at Fort Washington during the summer, when the river flow is small. This difference is not very large, however, and the curves of each station are strikingly parallel, proving that there is little lag. When the stream flow is greater the difference becomes smaller, and during the winter samples were taken farther down, at Whitestone Point. As purification progresses the absolute change becomes less, and it is necessary to take samples farther apart in order to get observable differences. During the winter this is especially true, since, the stream flow being greater, the distances represent smaller time factors.

Whitestone Point.—Whitestone Point is the beginning of "Wide Water." From Little Falls down to this point the river is a deep channel, fringed at places with shallow flats bearing considerable vegetation. Below this point the river broadens out into somewhat shallow basins, opening to wide inlets and bays, while the real bed of the river is deep. Time and dilution become the most important factors. Though samples were not collected at the next three stations during the summer, the results show that at this point the pollution had very largely disappeared. In the large volumes of water below the remaining pollution would undoubtedly soon be lost. In the winter the muddy contaminated water sweeps well into this area, and the effect of time was thoroughly studied. Moreover, the effect of the wind in these broad areas creates a considerable wave action, and this stirs up the mud at the bottom. The float tests made in this area show the marked effect of the wind in influencing and even in reversing the tidal currents.

Indianhead to Maryland Point.—In the stretch of 25 miles between Indianhead and Maryland Point there exist many factors of importance in the further elimination of pollution. In the first place the enormous volume of water introduces most strongly the factor of dilution. Secondly, Occoquan Creek ("Bull Run") enters the river below and nearly opposite Indianhead, forming what is known as Occoquan Bay. This tributary brings some additional pollution, but, what is more important, after every rain on its watershed its water is heavily charged with finely divided red clay, which defines the channel for miles along the main river. Third, in this area, at cross sections determined by the stream flow from the upper river and by tidal phases, and varying from its upper limit or above, to

about Smith's Point, occur the under run of salt water and the commingling of the two waters.

Within this area, therefore, occur enormous dilution, the introduction during freshets, when the time element is lessened, of a heavy suspension of finely divided matter, and of sea water, with its inability to carry large proportions of suspended matter. The stream flow is so small, compared with the total contents of this extensive area that, as the float observations show, the net down gain is very slight and the time element here most important. This area, therefore, is a great natural sedimentation basin, in which practically all of the pollution from the river above is disposed of.

About Maryland Point the river becomes quite salt and the precipitation of suspended matter is very apparent. The distance in time between this point and Possum Point is very great, even when the flow of the river is greatest. During a month of such flow there were less than seven *B. coli* per c. c., and in only three months did the number average more than one per. c. c.

An inspection of the garbage-disposal plant of the city of Washington, located at Cherry Hill on the Virginia shore in this area, and the result of bacteriological analyses of effluents and water from the shore show that, while the place might be considered a nuisance on account of the odors, there is little, if any, danger of infection therefrom.

Extending out for a mile or so from Maryland Point is a flat, probably the result of sedimentation due to the meeting of the sea and river waters. The river at Maryland Point makes a right angle turn to the east and the 10-mile stretch from here to Popes Creek, which is called "Nanjemoy Reach," is 1 mile wide. This area receives no additional pollution other than agricultural wash from the shores and the Machodoc.

Within this area the organisms remaining from the sewage of Washington and the upper river are so few that the effects of reinfection are relatively large. The upper portion was considered the last in the study of self-purification of pollution from those sources, for within the area any traces of sewage pollution which may remain are practically eliminated. In only one month was *B. coli* present in less than 1 c. c., of water, there having been 1.2 *B. coli* per c. c. in January. The nearest high month showed only 0.35.

Popes Creek.—At what has been termed the Popes Creek cross section, from Popes Creek to Mathias Point, the river again makes a right angle turn, this time to the south. At this point, on the Maryland side, the river receives the water from Port Tobacco Creek, in which there is some pollution from rural sources. Near its mouth and about Popes Creek there is a considerable wash from various

stock farms, the effects of which could be noticed in samples from the shore waters.

Popes Creek, 53 miles below Washington, is about the extreme upper limit of oyster beds in the Potomac River. The conditions as to saline content and food in the area between Popes Creek and Lower Cedar Point are favorable to the rapid growth of oyster spat, and from this area large numbers of oysters are taken for planting in waters of greater salinity. Oysters do not, as a rule, grow here to marketable size, owing to freshets which occur every year or so.

Lower Cedar Point to mouth of river.—From Lower Cedar Point to the mouth of the river, on both sides of the Potomac, in all of its estuaries, and on the "Kettle Bottom Shoals" in the middle of the river, the salinity of the water and its food content are most favorable to the propagation and growth of oysters. With the exception of small areas in the tributaries, which are rented to private planters by the States of Maryland and Virginia, all of these beds, which constitute one of the important natural shellfish areas of the country, are owned and policed by the two States. Hundreds of their citizens earn a livelihood from the large quantities of shellfish which they ship to all parts of the country, chiefly through Baltimore and Washington. Therefore elimination of the danger from infectious pollution reaching this area from the upper river and Washington would be of the utmost importance if such danger exists.

At Lower Cedar Point, during the month of the highest bacterial content here, there were only 0.25 *B. coli* per c. c., and the seasonal variation in this area is nowhere so striking as in upper region, the changes being probably due to local causes.

An analysis of the results of examination of oysters from all sections of the river and its tributaries, extending over an entire season, shows no single instance of dangerous pollution which may be attributed to the sewage from the river above the beds. An additional factor of safety, which is of interest and importance, is that during the winter period, when a large stream flow causes a decrease in the time element, the *B. coli* count in oysters does not increase with that in the water over the oyster beds, but is actually decreased. These results apparently confirm the observations of others as to the decrease in the functional activity of the oyster when the temperature is low. Subsequently these views have been definitely proven correct by a large number of direct observations at the Service experimental laboratory on Fisherman's Island.

A careful census was made of the boats and persons over the beds at the time when samples were taken, but the results show no pollution due to such cause. The dilution is enormous, the current over the beds is generally considerable, and the early diffusion so imper-

fect that the probability of finding such pollution is remote. Almost all of the vessels and small boats used in the industry retire to creeks and coves for safety during the night, and it is believed such places and times are generally chosen by their crews to attend to the ordinary calls of nature. The oysters in the tributaries were not bad, but in some instances, as a result of local pollution, generally from agricultural wash, showed higher bacterial scores than those from the Potomac River.

Colonial Beach, the only urban community on this section of the river, has a large population during the summer, but only 1,000 throughout the months when oysters are taken in considerable quantity. The sewage from this community is emptied, after some delay in a receiving chamber, into Monroe Bay. During the oyster season a very large number of vessels, with at times a floating population of several hundred, put into this bay every night for safety. As a result an amount of fresh sewage is deposited over or near the private beds therein, and, despite the fact that no very high scores were obtained from oysters from this area, there is manifest danger of infection from this source. It is believed that oysters therefrom should not be sold. There may be some danger also in the oysters taken from the immediate vicinity of the drain just below Rock Point, a picture of which is shown, and from the cove between the wharf and residence at Lewisetta, though the immediate dilution at both places is enormous, and few, if any, oysters are grown here.

A few samples from Nomini Creek showed some counts, apparently due to local wash from the bridge, though it may have been from the small community. The introduction of water carriage for sewage would render this stream liable to pollution. Such instances, however, represent only a small and inconsiderable part of the extensive oyster-bearing areas of the Potomac River and its tributaries. It is believed that oysters from sources other than those specifically indicated are free from infectious pollution.

The small cost and ease with which artesian water is secured in this region have resulted in an abundant and safe supply at nearly every wharf and shucking house along the shore of the lower river. The impression gained by the inspection and by conversation with physicians is that there has been a decrease in the typhoid fever rate during recent years, and that such fever as does occur is most frequently present during the summer months and not during the oyster season.

The evidence from Colonial Beach proves that during the past year no typhoid fever could in any way have been attributed to eating shellfish from this section.

SUMMARY OF RESULTS.

PROCEDURE AND SCOPE.

This report is the result of an investigation of the pollution of the Potomac River and its tributaries which was begun by the Public Health Service June 2, 1913, and continued until May 31, 1914. The investigation included a sanitary survey of the Potomac River watershed and laboratory studies of the water, mud, plankton, and shellfish. The sanitary survey included investigations as to the number of persons on the watershed, the prevalence and distribution of typhoid fever, the water supplies, sewage-disposal systems, and character and amounts of trade wastes.

As a result of the survey it was found that about 94.7 per cent of the population were served by public water supplies; that a smaller proportion, 38 per cent, were served by sewage-disposal systems. While typhoid fever was especially prevalent throughout the upper basin, the installation of water and sewerage systems and the increased activity of State and municipal health authorities have been followed by a decreasing typhoid rate, especially in the urban population; and the disease is now chiefly a rural one.

Following the investigation, intensive studies of sanitary conditions in certain sections and of important trade wastes are being, or have been, made by the Public Health Service. Laboratory studies were made of the conditions in the upper river, in the section from Piedmont to Cumberland, with special reference to the effect upon the sanitary conditions in the river and the effect upon them, and upon each other, of mine wastes and the effluent from pulp mills.

Throughout the time of the investigation an intensive study of the river was made from Great Falls to its mouth with special reference to possible excessive pollution and consequent nuisance in that portion of the river immediately near Washington and Alexandria, and with reference to the problems concerned in the self-purification of the river. Particular attention was given to the possibility of the spread of water-borne disease by shellfish taken from the beds in the lower portion of the river.

Laboratory studies were made in the Hygienic Laboratory, in a temporary laboratory installed at Colonial Beach, Va., on the service steamer *W. D. Bratton*, and for a month in the city laboratory at Cumberland, Md. These laboratory studies included 9,843 bacteriological analyses of water; 461 samples of shellfish for the determi-

nation of the *B. coli* and total bacterial counts; 129 samples of mud from the river, examined for chemical, bacteriological, and microscropical data; 149 samples of water examined for plankton determinations; 43 samples of aquatic plants investigated; and approximately 3,000 samples of water for determination of the dissolved oxygen, nitrite, nitrate, chlorine, and other chemical contents.

Daily analyses were made of sewage from the Washington Sewage Pumping Station. Bacteriological examination was also made of 99 samples of shellfish and 118 samples of water collected by the Bureau of Chemistry, and 55 samples of oysters and 15 aquatic plants collected by the *Bratton* from the Chesapeake Bay and various tributaries, for comparison with those from the Potomac River. The conclusions reached, therefore, are the result of the examination of 615 samples of oysters, 13,240 samples of water, 149 samples of mud, and 43 aquatic plants.

CONCLUSIONS.

The investigation showed:

1. That at no point above Washington is the water of the Potomac River safe for use as a public water supply without reasonable treatment.

2. That portions of the main or Georgetown Channel, between the Chain Bridge and the junction of the main channel with Anacostia River and Washington Channel, are so heavily polluted that the water is unsafe for bathing purposes. The water from this section supplies the Tidal Basin.

3. That the condition of that area in Anacostia River in the neighborhood of the sewage-pumping station and at the junction of the three channels is bad during hot weather, at times constituting a nuisance; but that, when the improvements now planned or under construction are completed, these conditions should no longer exist.

4. That at no time was the condition over and about the Washington sewer outlet such as to constitute a nuisance.

5. That even during the period of lowest stream flow and highest temperature the river in the area of heaviest pollution—that is, between Giesboro Point and Fort Foote—has at all times sufficient oxygen available for the sewage now discharged into the river, and enough to take care of the sewage which will probably be added for several years to come.

6. That in addition to the dissolved oxygen contained in the water of the river as it flows from the Great Falls, the great areas of flats on each side of the river for many miles act as oxygen generators. The amount of oxygen given off, depending in part upon the condition of plant life, turbidity, and sunshine, is therefore greatest during the summer, when there is the most need for it.

7. That in addition to releasing enormous volumes of ogygen, these flats are breeding places for plankton forms, which themselves materially assist by biological processes in the breaking down of sewage and the consequent purification of the river.

8. That the section of the river from Indianhead to Maryland Point, known as "Wide Water," is a great natural purification basin, in which the factors of time, dilution, oxidation, sedimentation due to irregularity in velocity and direction of current, and to the mingling of the sea and river waters, together with the biological processes, all unite to accomplish the death of intestinal organisms and the breaking down of sewage compounds.

As a consequence few intestinal organisms from above reach Maryland Point, and these disappear in the stretch of 10 miles between that point and Popes Creek, at which section evidence of pollution from the upper river has disappeared.

9. In an examination of oysters from all the beds in the whole river and its tributaries, extending over an entire season, no dangerously polluted oysters were found in the Potomac River proper. The very few polluted samples found came from localities from which few oysters are shipped.

Analysis of the results obtained during the year in the examination of shellfish and of water taken from over the oyster beds shows that the periods of highest *B. coli* count in the two were not coincident. The highest *B. coli* content of the water was found during those periods of winter when large stream flow reduced the time factor. The lowest *B. coli* content of the oysters was found during the same periods, when the temperature of the water was low.

10. While the time occupied in the transfer of continuously suspended matter from the Washington sewer outlets to the upper limits of the shellfish beds has not been determined by observations upon any float which traversed the whole area, nor by a sufficient number of floats over the lower area, it is certain that, even under conditions of ordinary high stream flow, such as prevail during the spring months, at least two or three weeks are ordinarily required for such transfer.

From the observations made April 27 and 28, 1914, it is evident that, under conditions of unusual flood, at least some portion of water would travel the distance in a much shorter period of time. The bacteriological results obtained, however, in the lower river after this flood give no evidence that excessive pollution reached that section even under such conditions. The gelatin counts, which so quickly indicate sudden changes, the 37° agar count, and the *B. coli* determinations upon water and oysters all show that between Possum Point and Popes Creek the pollution has been eliminated. Only

one sample at Popes Creek from April 24 to May 7 showed *B. coli* in 1 c. c., the average being less than 1 in 10 c. c.

11. Parallel series of hundreds of samples of sewage, of water, and of shellfish were studied to determine the value of the lactose bile presumptive test, and the relative values of lactose bile and lactose broth, as well as the usefulness of the endo medium and of lactose litmus agar for the determination of *B. coli.* Observations were also made as to the relative values of agar and of gelatin for the determination of the total bacterial count under varying conditions.

As a result of these studies it is recommended that the lactose bile presumptive test be not used, because of the unreliable results obtained therefrom; and that the use of lactose broth fermentation tubes, with confirmation on endo medium, be adopted as a routine procedure in the examination of water and shellfish for the determination of the presence of *B. coli.*

The presence and significance of anaerobic spore-bearing lactose-splitting organisms has been studied; it has been shown that the presence of such organisms does not necessarily indicate recent or dangerous pollution, and that they are of little sanitary significance. The somewhat constant and close relationship between *B. coli* and total counts on nutrient agar at 37° is discussed, as well as the value of gelatin in showing sudden changes in river conditions.

An analysis of the samples has been made for the purpose of determining the death rate of *B. coli* under varying conditions of time and temperature, such as have existed in the Potomac River.

During the study of self-purification of the Potomac River the most striking fact brought out was the enormous variation in bacterial conditions at the sampling stations during different periods of the year.

When considered individually the results appear quite inexplicable, but when the factor of time is taken into consideration they fall into an orderly array and may be accounted for by variations in stream flow. The results may be explained by the rational theory that, under similar conditions, approximately the same percentage purification takes place in equal times. The death rate of *B. coli* is increased by higher temperatures during the summer months, and is greater in freshly polluted water.

12. That notwithstanding the especially favorable natural conditions attending the present disposal by dilution of the sewage of the District of Columbia it is inevitable that, in consequence of a continued increase in the population of the District of Columbia, the capacity of the river to dispose of sewage without nuisance or danger will eventually be overtaxed. It is therefore desirable that primary treatment works should be installed in the near future sufficient to clarify the sewage up to the limits to which plain sedi-

mentation may be advantageously carried. The cost of construction and operation of these treatment works would not be such as to be prohibitive when considered in connection with the benefits to be derived. They should be so designed as to work in harmony with the favorable conditions locally afforded by nature for sewage disposal. These works should be sufficient to maintain a reasonable constant as to the amount of organic matter dependent on the river for purification. Their construction is also desirable in recognition of the advancing standards as to hygienic cleanliness of river waters, as well as for the example in such matters which should be afforded by the national capital.

To the end that necessary basic data for the design of such works may be available when needed and that the latest advances in sewage disposal may be properly investigated as applied to the Washington sewage, it is desirable that provision be made at the present time for definite experimental field studies. Such provision should take the form of a small sewage testing station equipped with experimental tanks and other devices suitable for these studies. The data obtained would be of the greatest immediate value in its application to the particular problems of the District of Columbia, and such a station would also be in position to investigate and report upon many of the newer processes of sewage treatment which are being advanced from time to time, and upon the merits of which there is entirely insufficient information. The gathering of such information would be of nation-wide importance.

HYGIENIC LABORATORY BULLETINS OF THE PUBLIC HEALTH SERVICE.

The Hygienic Laboratory was established in New York, at the Marine Hospital on Staten Island, August, 1887. It was transferred to Washington, with quarters in the Butler Building, June 11, 1891, and a new laboratory building, located in Washington, was authorized by act of Congress March 3, 1901.

The following *bulletins* [Bulls. Nos. 1–7, 1900 to 1902, Hyg. Lab., U. S. Mar.-Hosp. Serv., Wash.] have been issued:

*No. 1.—Preliminary note on the viability of the *Bacillus pestis*. By M. J. Rosenau.

No. 2.—Formalin disinfection of baggage without apparatus. By M. J. Rosenau.

*No. 3.—Sulphur dioxid as a germicidal agent. By H. D. Geddings.

*No. 4.—Viability of the *Bacillus pestis*. By M. J. Rosenau.

No. 5.—An investigation of a pathogenic microbe (*B. typhi murium* Danyz) applied to the destruction of rats. By M. J. Rosenau.

*No. 6.—Disinfection against mosquitoes with formaldehyde and sulphur dioxid. By M. J. Roesnau.

†No. 7.—Laboratory technique: Ring test for indol, by S. B. Grubbs and Edward Francis; Collodium sacs, by S. B. Grubbs and Edward Francis; Microphotography with simple apparatus, by H. B. Parker.

By act of Congress approved July 1, 1902, the name of the "United States Marine-Hospital Service" was changed to the "Public Health and Marine-Hospital Service of the United States," and three new divisions were added to the Hygienic Laboratory.

Since the change of name of the service the bulletins of the Hygienic Laboratory have been continued in the same numerical order as follows:

*No. 8.—Laboratory course in pathology and bacteriology. By M. J. Rosenau. (Revised edition, March, 1904.)

†No. 9.—Presence of tetanus in commercial gelatin. By John F. Anderson.

*No. 10.—Report upon the prevalence and geographic distribution of hookworm disease (uncinariasis or anchylostomiasis) in the United States. By Ch. Wardell Stiles.

*No. 11.—An experimental investigation of *Trypanosoma lewisi*. By Edward Francis.

*No. 12.—The bacteriological impurities of vaccine virus; an experimental study. By M. J. Rosenau.

*No. 13.—A statistical study of the intestinal parasites of 500 white male patients at the United States Government Hospital for the Insane; by Philip E. Garrison, Brayton H. Ransom, and Earle C. Stevenson. A parasitic roundworm (*Agamomermis culicis* n. g., n. sp.) in American mosquitoes (*Culex sollicitans*); by Ch. Wardell Stiles. The type species of the cestode genus *Hymenolepis;* by Ch. Wardell Stiles.

*No. 14.—Spotted fever (tick fever) of the Rocky Mountains; a new disease. By John F. Anderson.

*No. 15.—Inefficiency of ferrous sulphate as an antiseptic and germicide. By Allen J. McLaughlin.

*No. 16.—The antiseptic and germicidal properties of glycerin. By M. J. Rosenau.

*No. 17.—Illustrated key to the trematode parasites of man. By Ch. Wardell Stiles.

*No. 18.—An account of the tapeworms of the genus *Hymenolepis* parasitic in man, including reports of several new cases of the dwarf tapeworm (*H. nana*) in the United States. By Brayton H. Ransom.

*No. 19.—A method for inoculating animals with precise amounts. By M. J. Rosenau.

*No. 20.—A zoological investigation into the cause, transmission, and source of Rocky Mountain "spotted fever." By Ch. Wardell Stiles.

*No. 21.—The immunity unit for standardizing diphtheria antitoxin (based on Ehrlich's normal serum). Official standard prepared under the act approved July 1, 1902. By M. J. Rosenau.

*No. 22.—Chloride of zinc as a deodorant, antiseptic, and germicide. By T. B. McClintic.

*No. 23.—Changes in the Pharmacopœia of the United States of America. Eighth decennial revision. By Reid Hunt and Murray Galt Motter.

No. 24.—The International Code of Zoological Nomenclature as applied to medicine. By Ch. Wardell Stiles.

*No. 25.—Illustrated key to the cestode parasites of man. By Ch. Wardell Stiles.

*No. 26.—On the stability of the oxidases and their conduct toward various reagents. The conduct of phenolphthalein in the animal organism. A test for saccharin, and a simple method of distinguishing between cumarin and vanillin. The toxicity of ozone and other oxidizing agents to lipase. The influence of chemical constitution on the lipoytic hydrolysis of etheral salts. By J. H. Kastle.

*No. 27.—The limitations of formaldehyde gas as a disinfectant with special reference to car sanitation. By Thomas B. McClintic.

*No. 28.—A statistical study of the prevalence of intestinal worms in man. By Ch. Wardell Stiles and Philip E. Garrison.

No. 29.—A study of the cause of sudden death following the injection of horse serum. By M. J. Rosenau and John F. Anderson.

†No. 30.—I. Maternal transmission of immunity to diphtheria toxine. II. Maternal transmission of immunity to diphtheria toxine and hypersusceptibility to horse serum in the same animal. By John F. Anderson.

†No. 31.—Variations in the peroxidase activity of the blood in health and disease. By Joseph H. Kastle and Harold L. Amoss.

†No. 32.—A stomach lesion in guinea pigs caused by diphtheria toxine and its bearing upon experimental gastric ulcer. By M. J. Rosenau and John F. Anderson.

*No. 33.—Studies in experimental alcoholism. By Reid Hunt.

†No. 34.—I. *Agamofilaria georgiana* n. sp., an apparently new roundworm parasite from the ankle of a negress. II. The zoological characters of the roundworm genus *Filaria* Mueller, 1787. III. Three new American cases of infection of man with horsehair worms (species *Paragordius varius*), with summary of all cases reported to date. By Ch. Wardell Stiles.

†No. 35.—Report on the origin and prevalence of typhoid fever in the District of Columbia. By M. J. Rosenau, L. L. Lumsden, and Joseph H. Kastle. (Including articles contributed by Ch. Wardell Stiles, Joseph Goldberger, and A. M. Stimson.)

†No. 36.—Further studies upon hypersusceptibility and immunity. By M. J. Rosenau and John F. Anderson.

†No. 37.—Index-catalogue of medical and veterinary zoology. Subjects: Trematoda and trematode diseases. By Ch. Wardell Stiles and Albert Hassall.

No. 38.—The influence of antitoxin upon post-diptheritic paralysis. By M. J. Rosenau and John F. Anderson.

†No. 39.—The antiseptic and germicidal properties of solutions of formaldehyde and their actions upon toxines. By John F. Anderson.

†No. 40.—1. The occurrence of a proliferating cestode larva (*Sparganum proliferum*) in man in Florida, by Ch. Wardell Stiles. 2. A reexamination of the type specimen of *Filaria restiformis* Leidy, 1880=*Agamomermis restiformis*, by Ch. Wardell Stiles. 3. Observations on two new parasitic trematode worms: *Homalogaster philippinensis* n. sp., *Agamodistomum nanus* n. sp., by Ch. Wardell Stiles and Joseph Goldberger. 4. A reexamination of the original specimen of *Tænia saginata abietina* (Weinland, 1858), by Ch. Wardell Stiles and Joseph Goldberger.

†No. 41.—Milk and its relation to the public health. By various authors.

†No. 42.—The thermal death points of pathogenic microorganisms in milk. By M. J. Rosenau.

†No. 43.—The standardization of tetanus antitoxin (an American unit established under authority of the act of July 1, 1902). By M. J. Rosenau and John F. Anderson.

No. 44.—Report No. 2 on the origin and prevalence of typhoid fever in the District of Columbia, 1907. By M. J. Rosenau, L. L. Lumsden, and Joseph H. Kastle.

†No. 45.—Further studies upon anaphylaxis. By M. J. Rosenau and John F. Anderson.

No. 46.—*Hepatozoon perniciosum* (n. g., n. sp.); a hæmogregarine pathogenic for white rats; with a description of the sexual cycle in the intermediate host, a mite (*lelaps echidnimus*). By W. W. Miller.

No. 47.—Studies on thyroid: I. The relation of iodine to the physiological activity of thyroid preparations. By Reid Hunt and Atherton Seidell.

No. 48.—The physiological standardization of digitalis. By Charles Wallis Edmunds and Worth Hale.

No. 49.—Digest of comments on the United States Pharmacopœia. Eighth decennial revision for the period ending December 31, 1905. By Murray Galt Motter and Martin I. Wilbert.

No. 50.—Further studies upon the phenomenon of anaphylaxis. By M. J. Rosenau and John F. Anderson.

No. 51.—Chemical tests for blood. By Joseph H. Kastle.

No. 52.—Report No. 3 on the origin and prevalence of typhoid fever in the District of Columbia (1908). By M. J. Rosenau, Leslie L. Lumdsen, and Joseph H. Kastle.

No. 53.—The influence of certain drugs upon the toxicity of acetanilide and antipyrine. By Worth Hale.

No. 54.—The fixing power of alkaloids on volatile acids and its application to the estimation of alkaloids with the aid of phenolphthalein or by the Volhard method. By Elias Elvove.

No. 55.—Quantitative pharmacological studies; adrenalin and adrenalinlike bodies. By W. H. Schultz.

No. 56.—Milk and its relation to the public health. (Revised edition of Bulletin No. 41). By various authors.

No. 57.—I. The presence of tubercle bacilli in the circulating blood in clinical and experimental tuberculosis. By John F. Anderson. II. The viability of the tubercle bacillus. By M. J. Rosenau.

No. 58.—Digest of comments on the Pharmacopœia of the United States of America (eighth decennial revision) and the National Formulary for the period ending December 31, 1906. By Murray Galt Motter and Martin I. Wilbert.

No. 59.—The oxidases and other oxygen catalysts concerned in biological oxidations. By Joseph Hoeing Kastle.

No. 60.—A study of the anatomy of Watsonius (n. g.), Watsoni of man, and of 19 allied species of mammalian trematode worms of the superfamily Paramphistomoidea. By Ch. Wardell Stiles and Joseph Goldberger.

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No. 62.—The taxonomic value of the miscroscopic structure of the stigmal plates in the tick genus *Dermacentor*. By Ch. Wardell Stiles.

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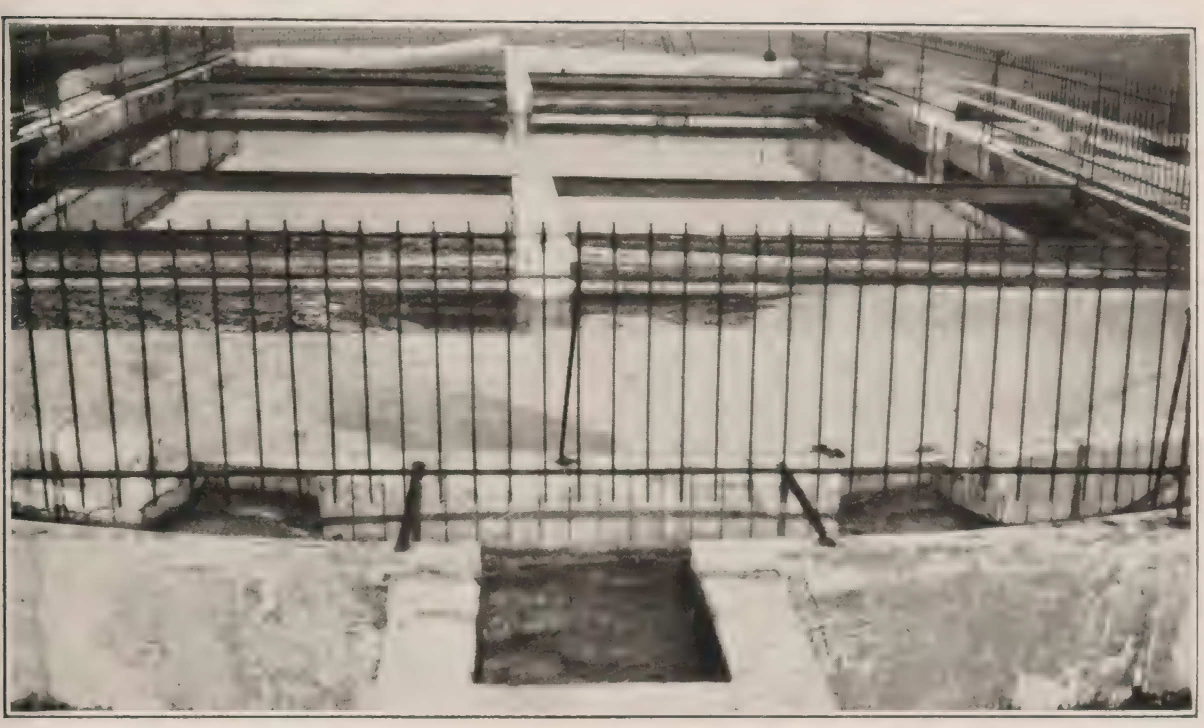

FIG. 1.—SEWAGE-DISPOSAL PLANT AT CHAMBERSBURG, PA. IMHOFF TANK.

FIG. 2.—SEWAGE-DISPOSAL PLANT AT CHAMBERSBURG, PA. SPRINKLING FILTERS.

FIG. 3.—SEWAGE-DISPOSAL PLANT AT CHAMBERSBURG, PA. FINAL SEDIMENTATION TANKS.

FIG. 4.—SEWAGE-DISPOSAL PLANT AT CHAMBERSBURG, PA. SLUDGE BEDS.

FIG. 5.—SEWAGE-DISPOSAL PLANT AT WINCHESTER, VA. INTERMITTENT SAND FILTRATION.

FIG. 6.—OUTLET OF SEWER SHOWING LARGE AMOUNT OF SCUM. HARRISONBURG, VA.

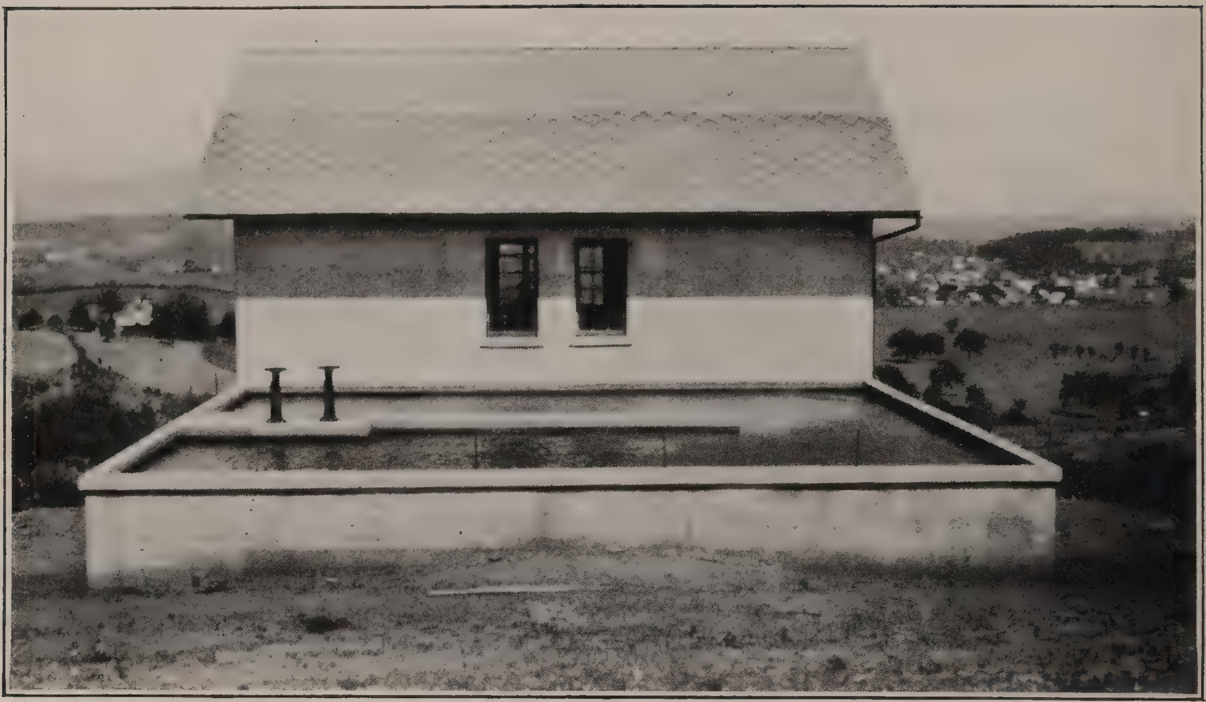

FIG. 7.—RAPID SAND FILTRATION PLANT, FRONT ROYAL, VA. THE TOWN CAN BE SEEN IN THE BACKGROUND.

FIG. 8.—DREDGE USED IN COLLECTING SAMPLES OF OYSTERS.

FIG. 9.—TYPE OF BOATS USED FOR OYSTER DREDGING.

FIG. 10.—OYSTER TONGERS AT WORK.

FIG. 11.—BOTTLEHOLDER FOR TAKING SURFACE SAMPLES.

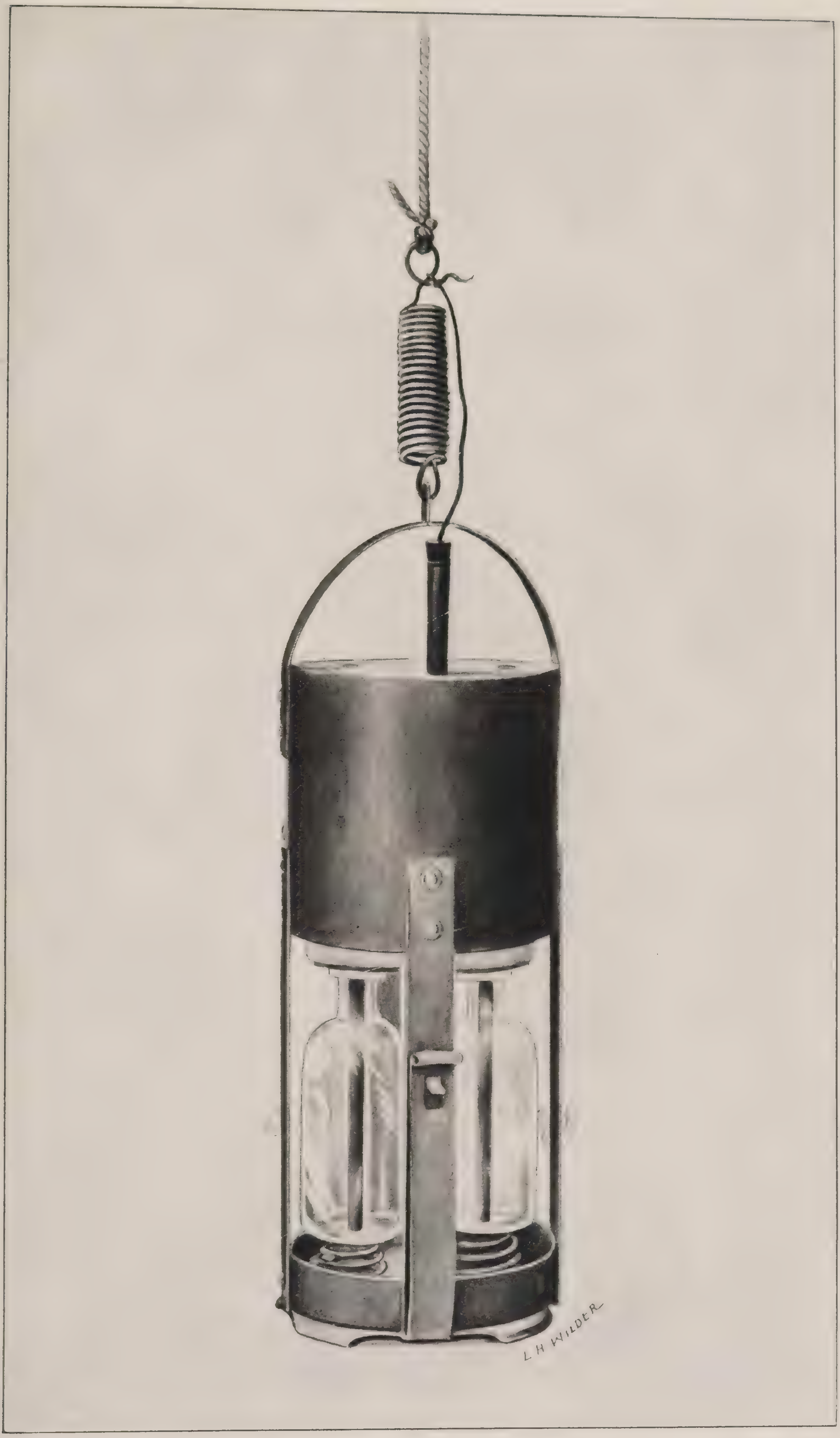

FIG. 12.—VIEW OF APPARATUS DESIGNED FOR THE COLLECTION OF DISSOLVED OXYGEN.

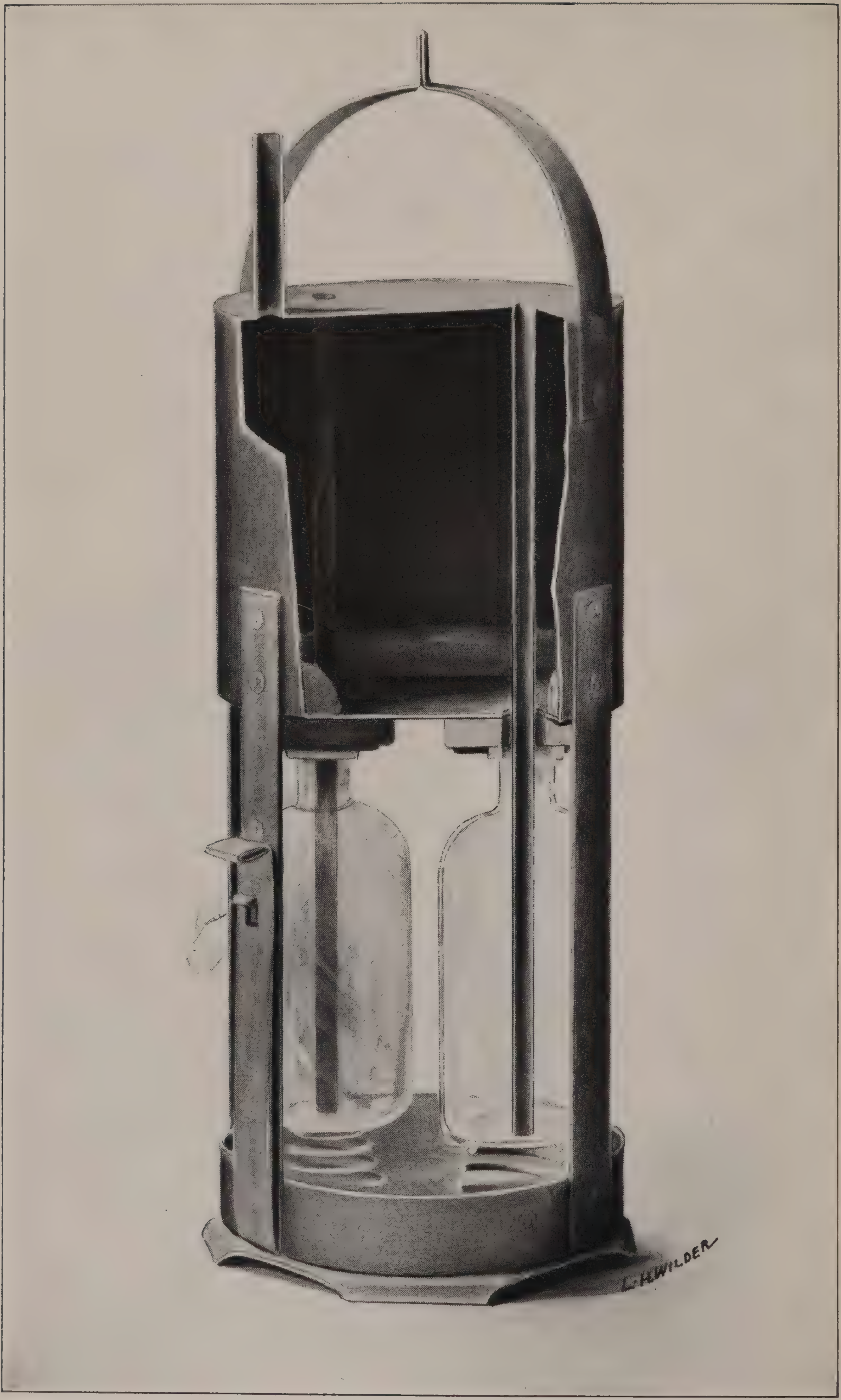

FIG. 13.—SECTIONAL VIEW OF APPARATUS DESIGNED FOR THE COLLECTION OF DUPLICATE SAMPLES FOR THE DETERMINATION OF DISSOLVED OXYGEN.

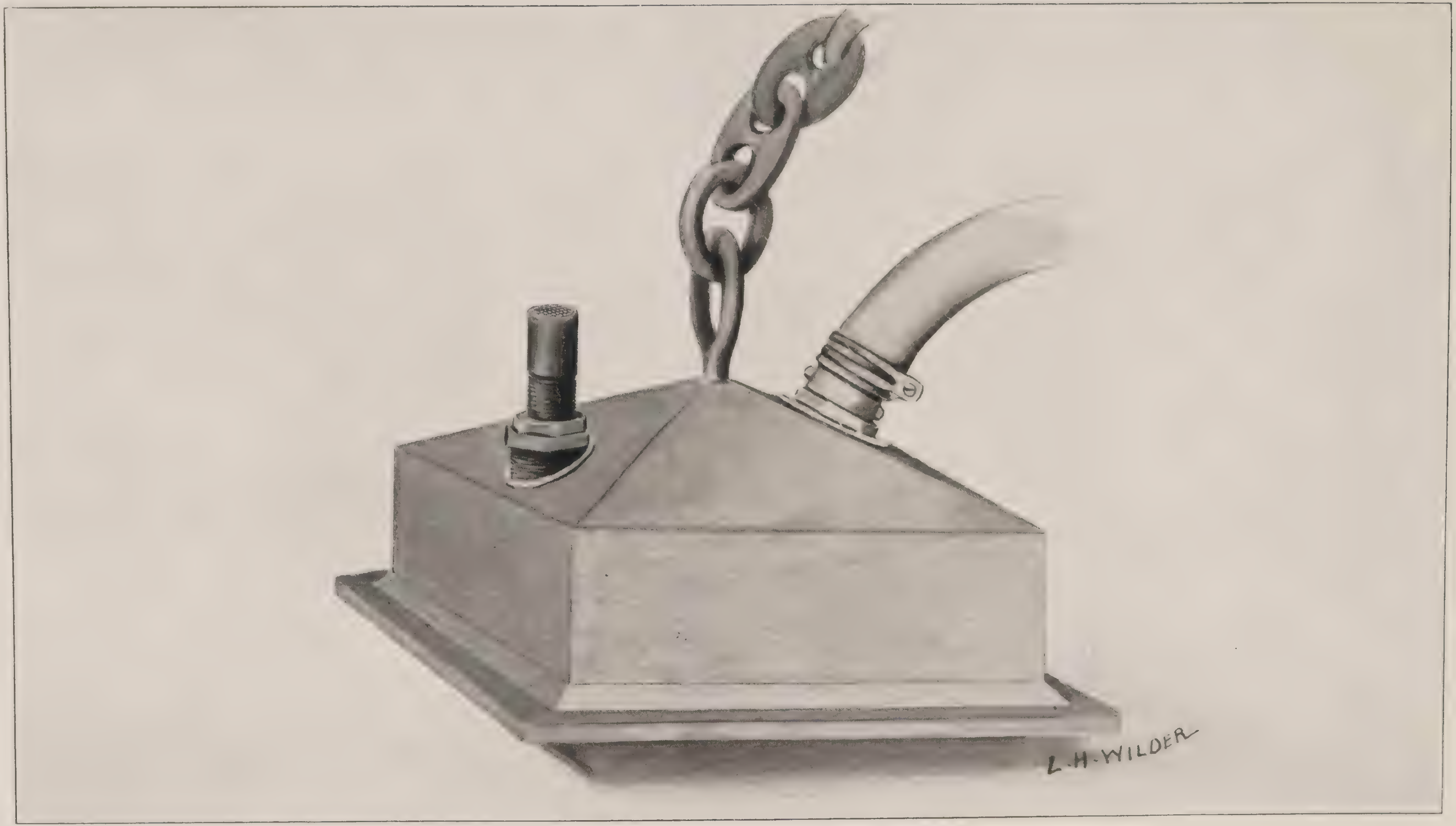

FIG. 14.—APPARATUS FOR THE COLLECTION OF SAMPLES OF MUD (OUTSIDE VIEW).

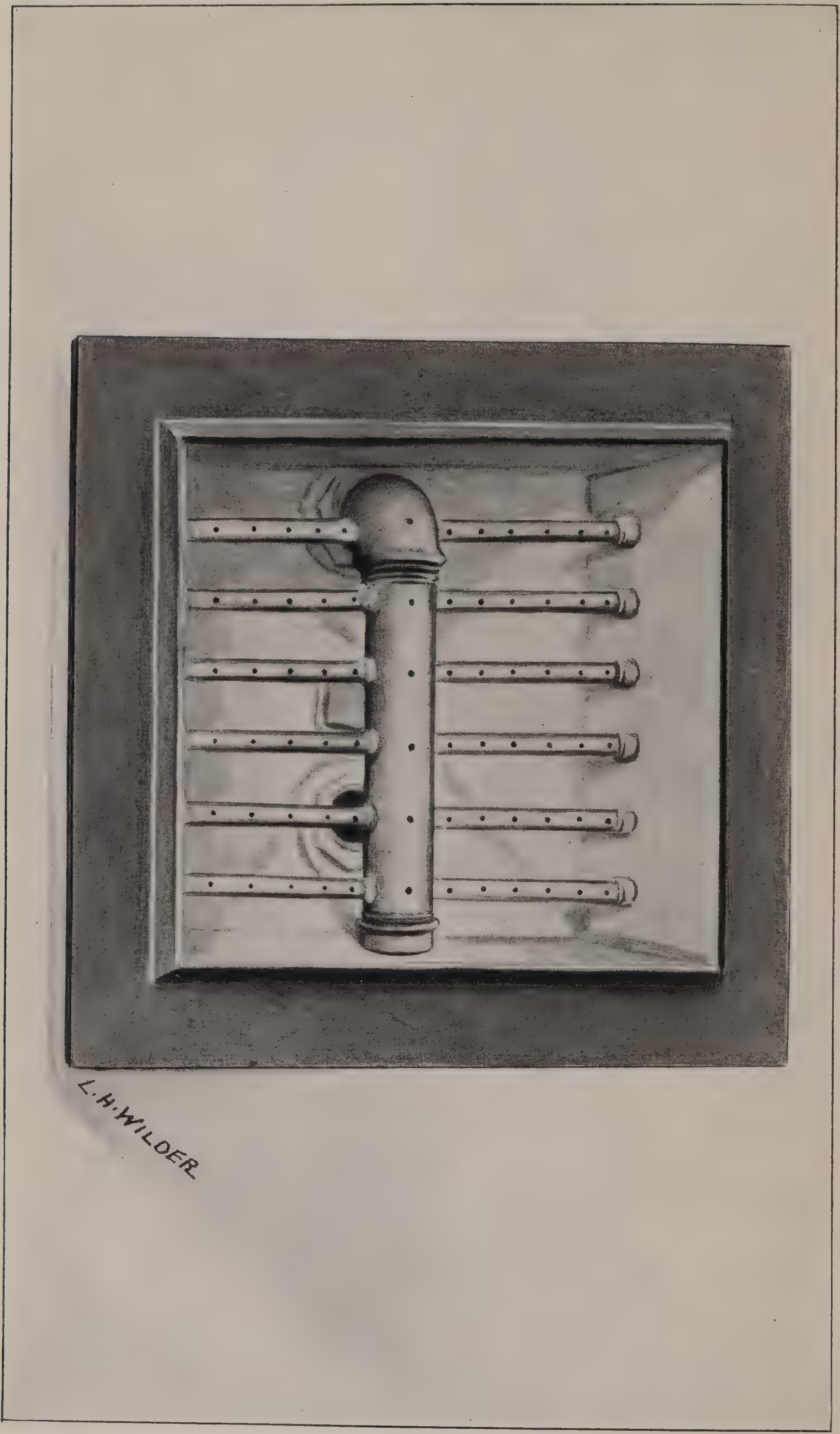

FIG. 15.—APPARATUS FOR THE COLLECTION OF SAMPLES OF MUD (INSIDE VIEW).

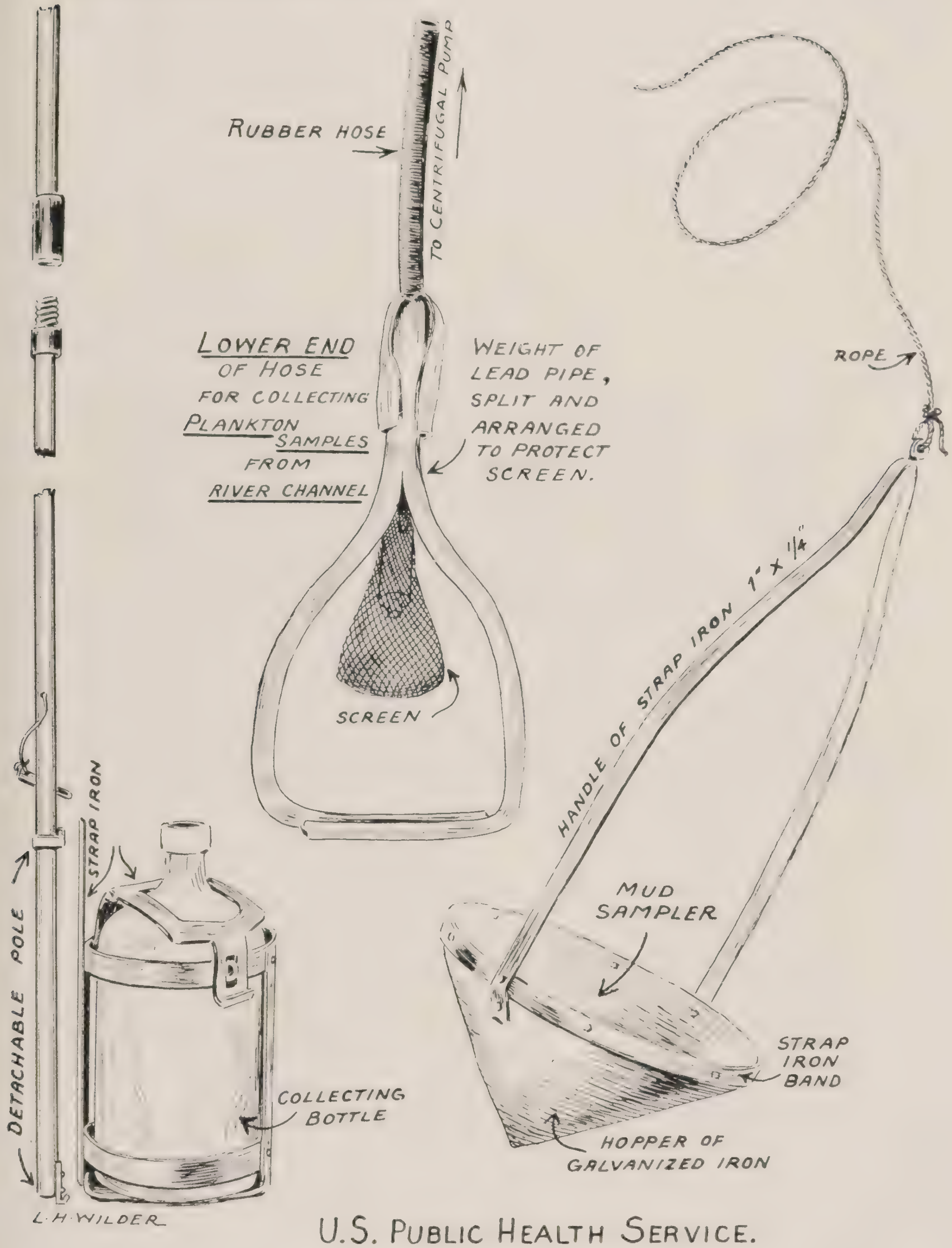

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FIG. 16.—APPARATUS USED IN COLLECTING SAMPLES.

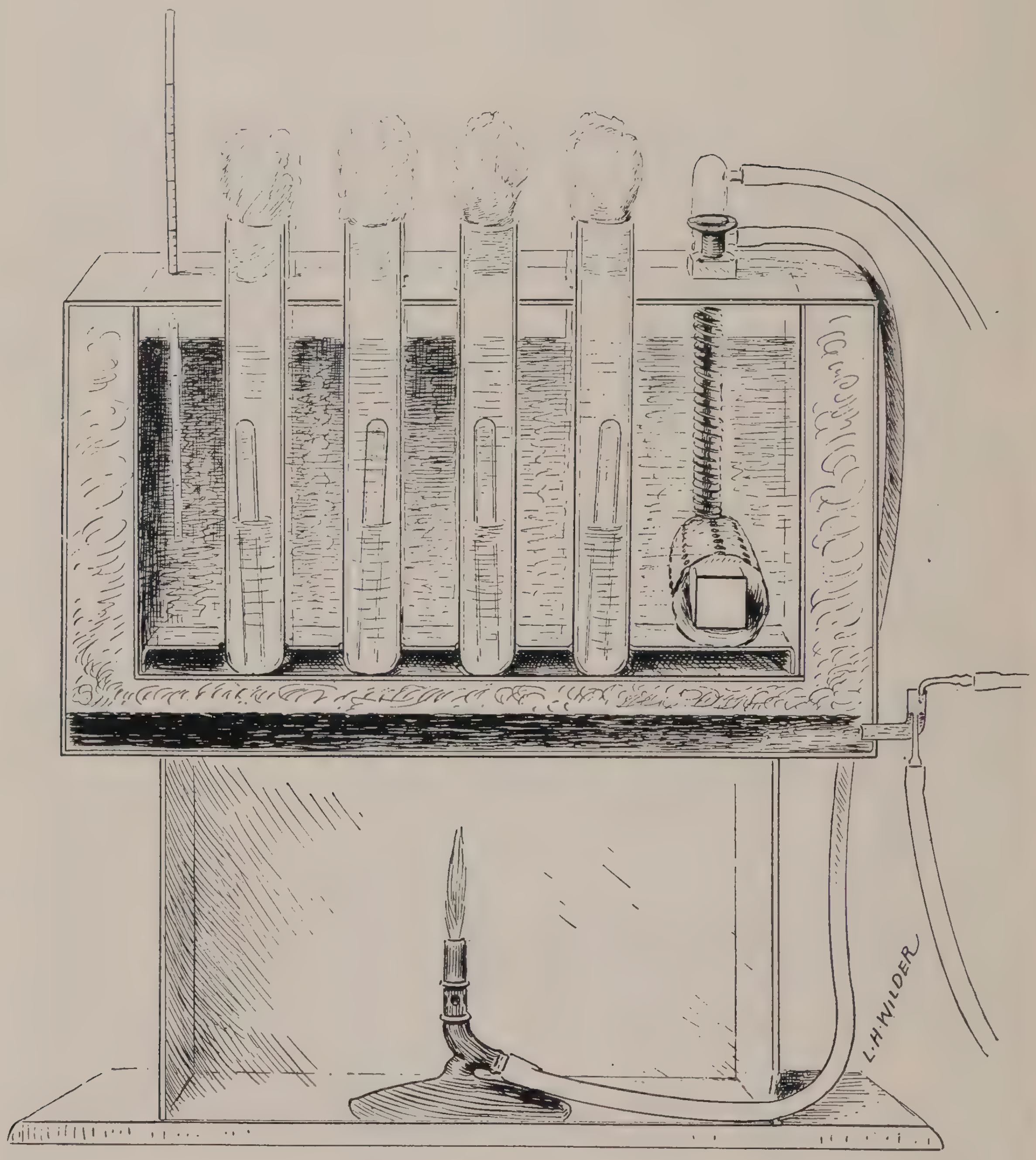

FIG. 17.—APPARATUS DESIGNED AND USED FOR THE ISOLATION OF SPORE-FORMING, LACTOSE-SPLITTING, AND GAS-FORMING ORGANISMS.

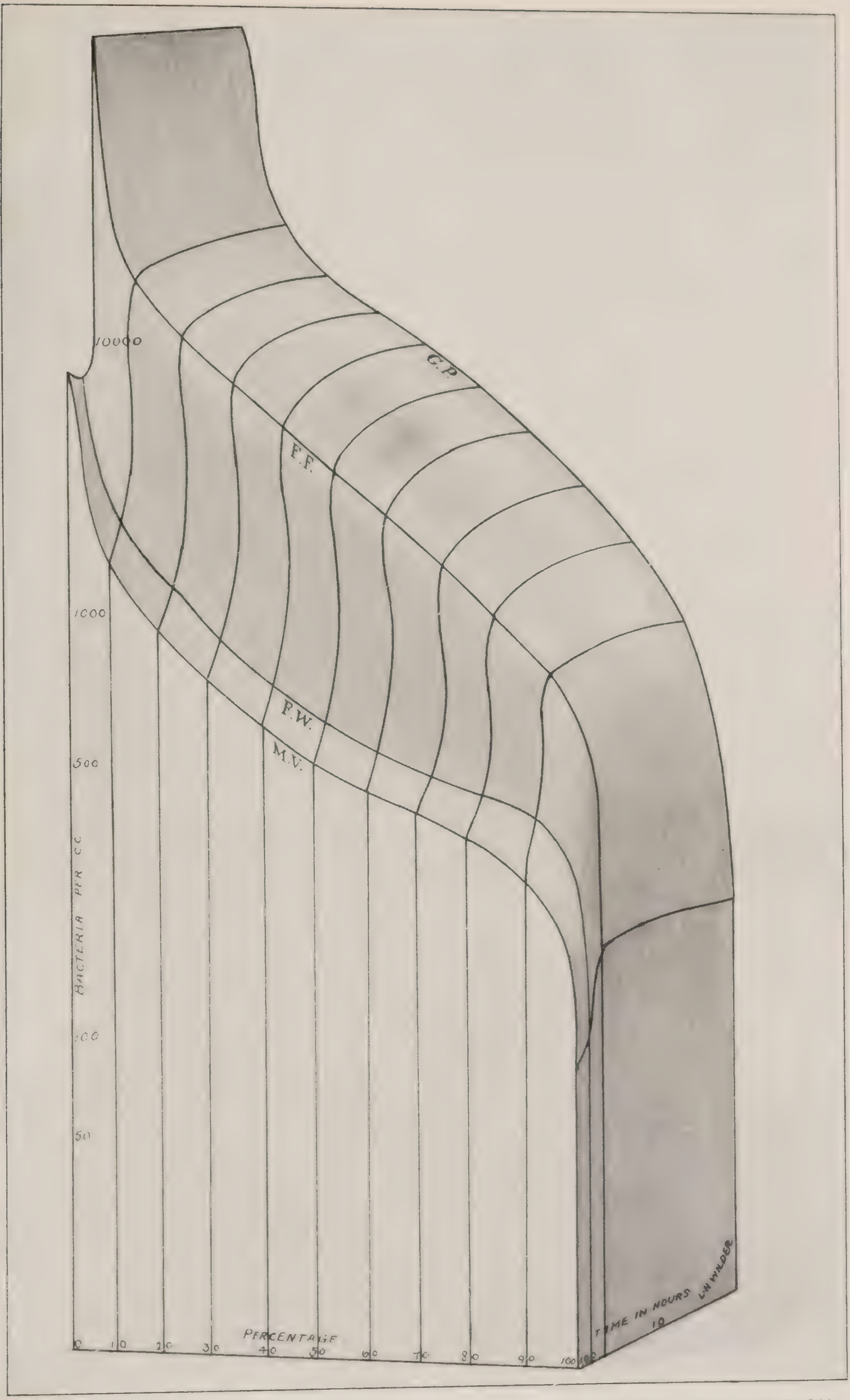

FIG. 18.—SOLID MODEL SHOWING BY QUARTERLY PERIODS THE DISTRIBUTION OF AGAR COUNTS IN RELATION TO STATIONS AND TIME; JUNE, JULY, AND AUGUST.

G. P., Giesboro Point; F. F., Fort Foote; F. W., Fort Washington; M. V., Mount Vernon; M. H., Marshall Hall; W. P., Whitestone Point; I. H., Indian Head; P. P., Possum Point; M. P., Maryland Point; P. C., Popes Creek; L. C. P., Lower Cedar Point; B. L. C. P., Sections below Lower Cedar Point.

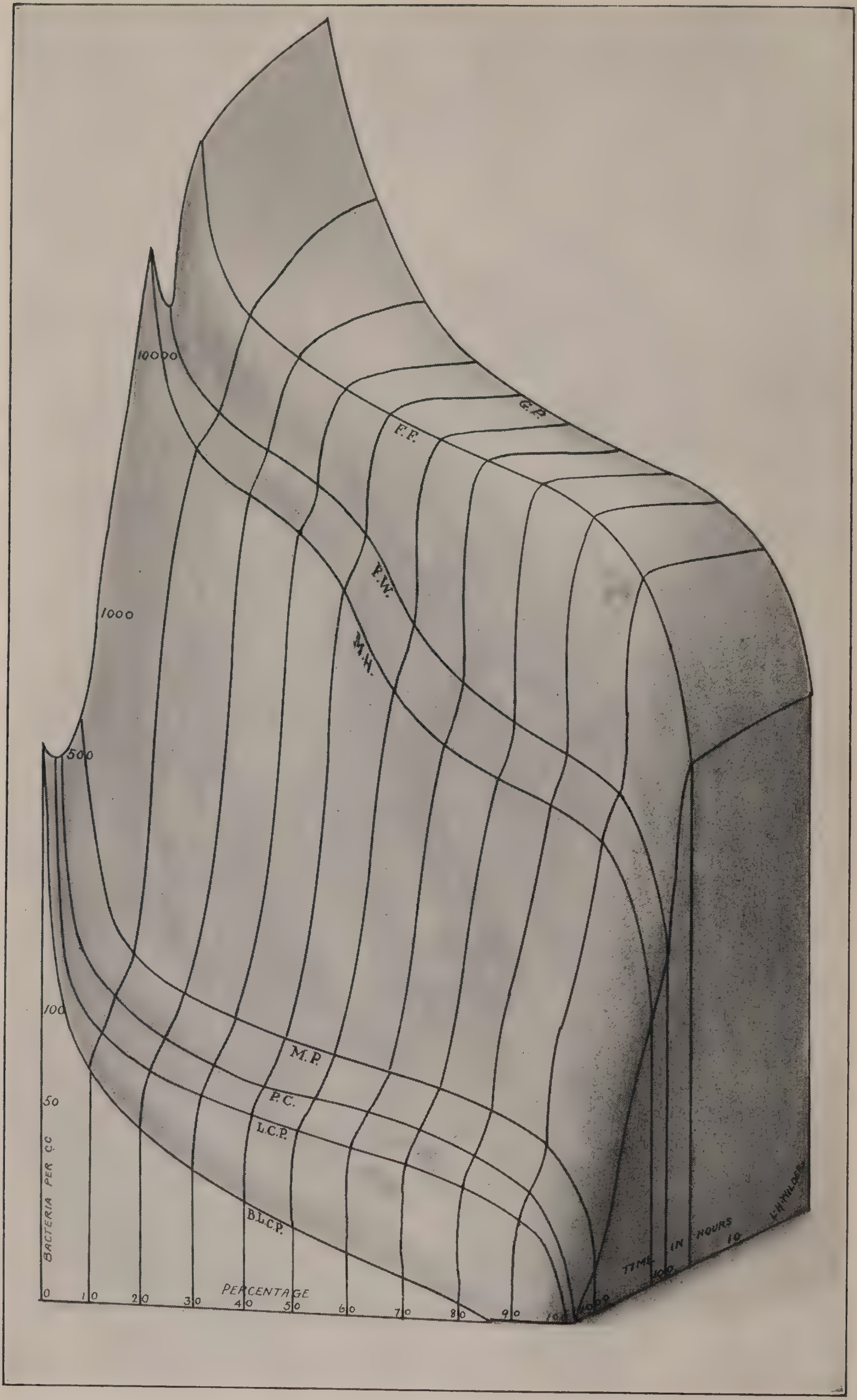

FIG. 19.—SOLID MODEL SHOWING BY QUARTERLY PERIODS THE DISTRIBUTION OF AGAR COUNTS IN RELATION TO STATIONS AND TIME; SEPTEMBER, OCTOBER, AND NOVEMBER.

G. P., Giesboro Point; F. F., Fort Foote; F. W., Fort Washington; M. V., Mount Vernon; M. H., Marshall Hall; W. P., Whitestone Point; I. H., Indian Head; P. P., Possum Point; M. P., Maryland Point; P. C., Popes Creek; L. C. P., Lower Cedar Point; B. L. C. P., Sections below Lower Cedar Point.

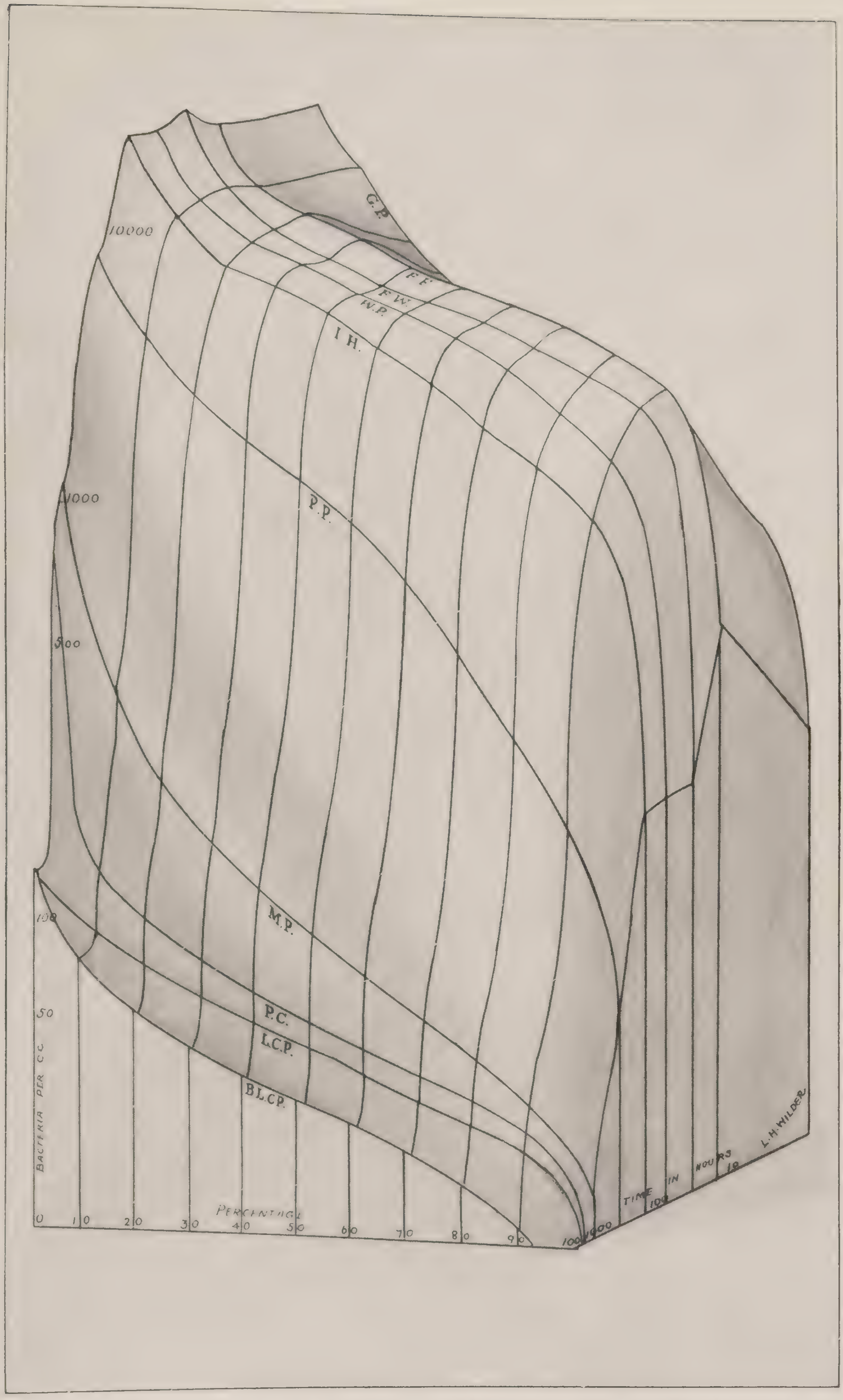

FIG. 20.—SOLID MODEL SHOWING BY QUARTERLY PERIODS THE DISTRIBUTION OF AGAR COUNTS IN RELATION TO STATIONS AND TIME; DECEMBER, JANUARY, AND FEBRUARY.

G. P., Giesboro Point; F. F., Fort Foote; F. W., Fort Washington; M. V., Mount Vernon; M. H., Marshall Hall; W. P., Whitestone Point; I. H., Indian Head; P. P., Possum Point; M. P., Maryland Point; P. C., Popes Creek; L. C. P., Lower Cedar Point; B. L. C. P., Sections below Lower Cedar Point.

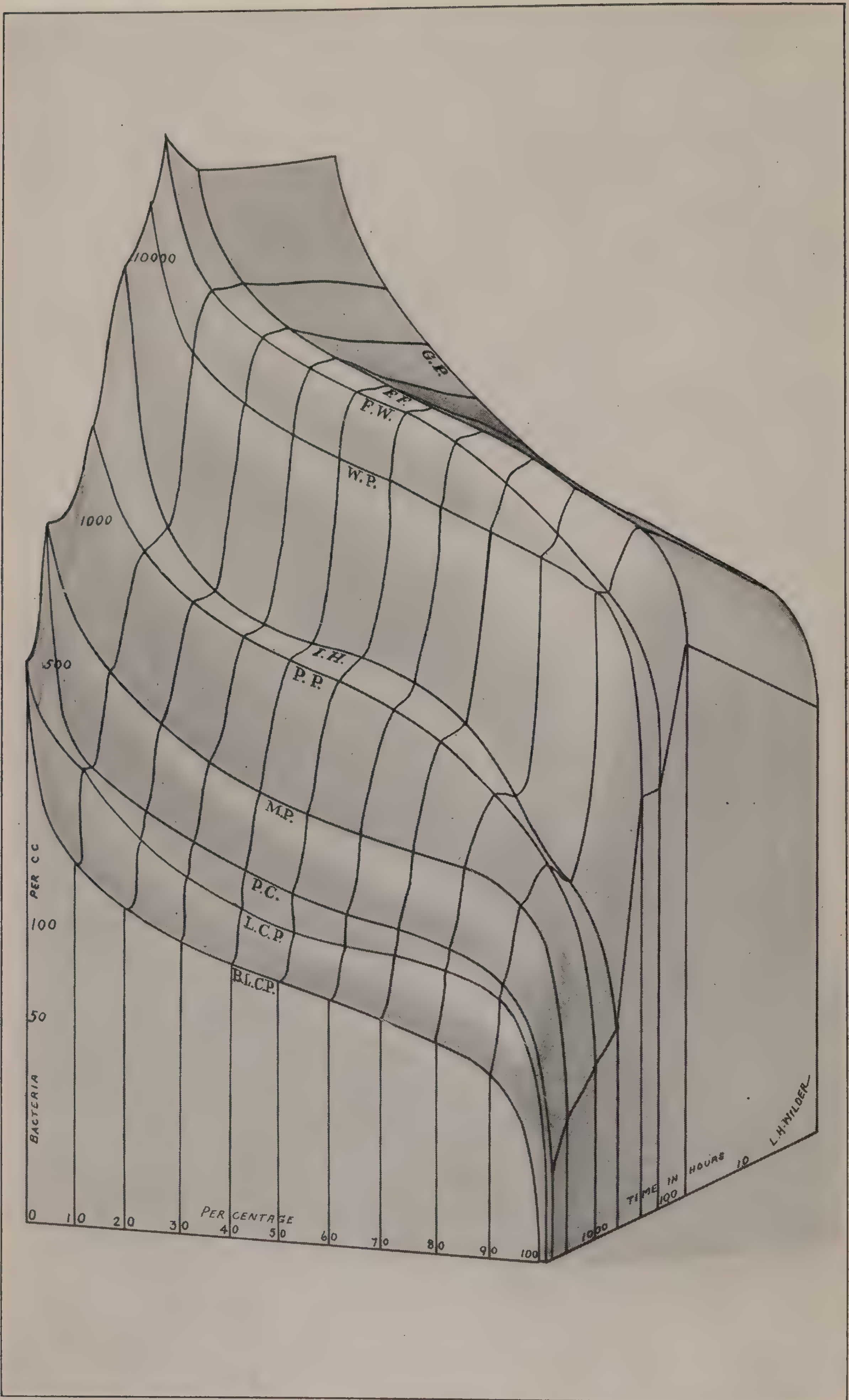

FIG. 21.—SOLID MODEL SHOWING BY QUARTERLY PERIODS THE DISTRIBUTION OF AGAR COUNTS IN RELATION TO STATIONS AND TIME; MARCH, APRIL, AND MAY.

G. P., Giesboro Point; F. F., Fort Foote; F. W., Fort Washington; M. V., Mount Vernon; M. H., Marshall Hall; W. P., Whitestone Point; I. H., Indian Head; P. P., Possum Point; M. P., Maryland Point; P. C., Popes Creek; L. C. P., Lower Cedar Point; B. L. C. P., Sections below Lower Cedar Point.

FIG. 22.—ELODEA CANADENSIS.

FIG. 23.—MYRIOPHYLLUM.

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FIG. 24.—CERATOPHYLLUM (BUDS).

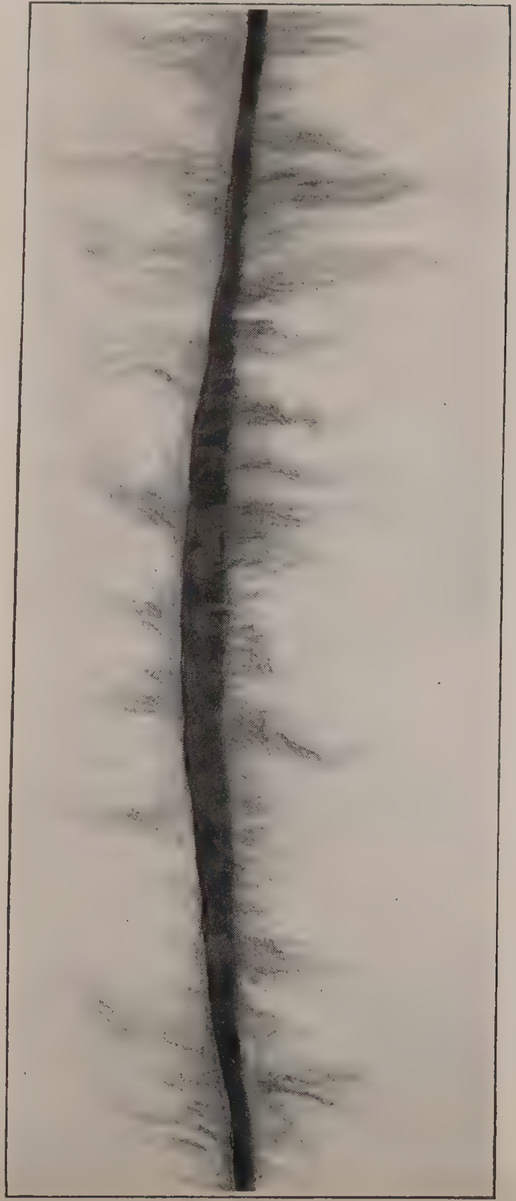

FIG. 25.—SPIROGYRA ON A BIT OF EELGRASS.

FIG. 26.—RIVULARIA ON POTAMOGETON.

L. H. Wilder.

FIG. 27.—MINUTE ALGAE ON POTAMOGETON.

FIG. 29.—POTAMOGETON CRISPUS.

FIG. 28.—VALLISNERIA SPIRALIS (EELGRASS).

L. H. Wilder.

FIG. 30.—GOMPHONEMA.
FIG. 32.—BODO SALTANS.
FIG. 34.—LIMNODRILUS.

FIG. 31.—SPHAEROTILUS.
FIG. 33.—SAPROLEZNIA.
FIG. 35.—EUGLENA.

FIG. 36.—BEGGIATOA.
FIG. 37.—PARAMOECIUM AND COLPIDIUM.
FIG. 38.—CARCHESIUM.
FIG. 39.—DIFFLUGIA.
FIG. 40.—CLADOPHORA.
FIG. 41.—RIVULARIA.

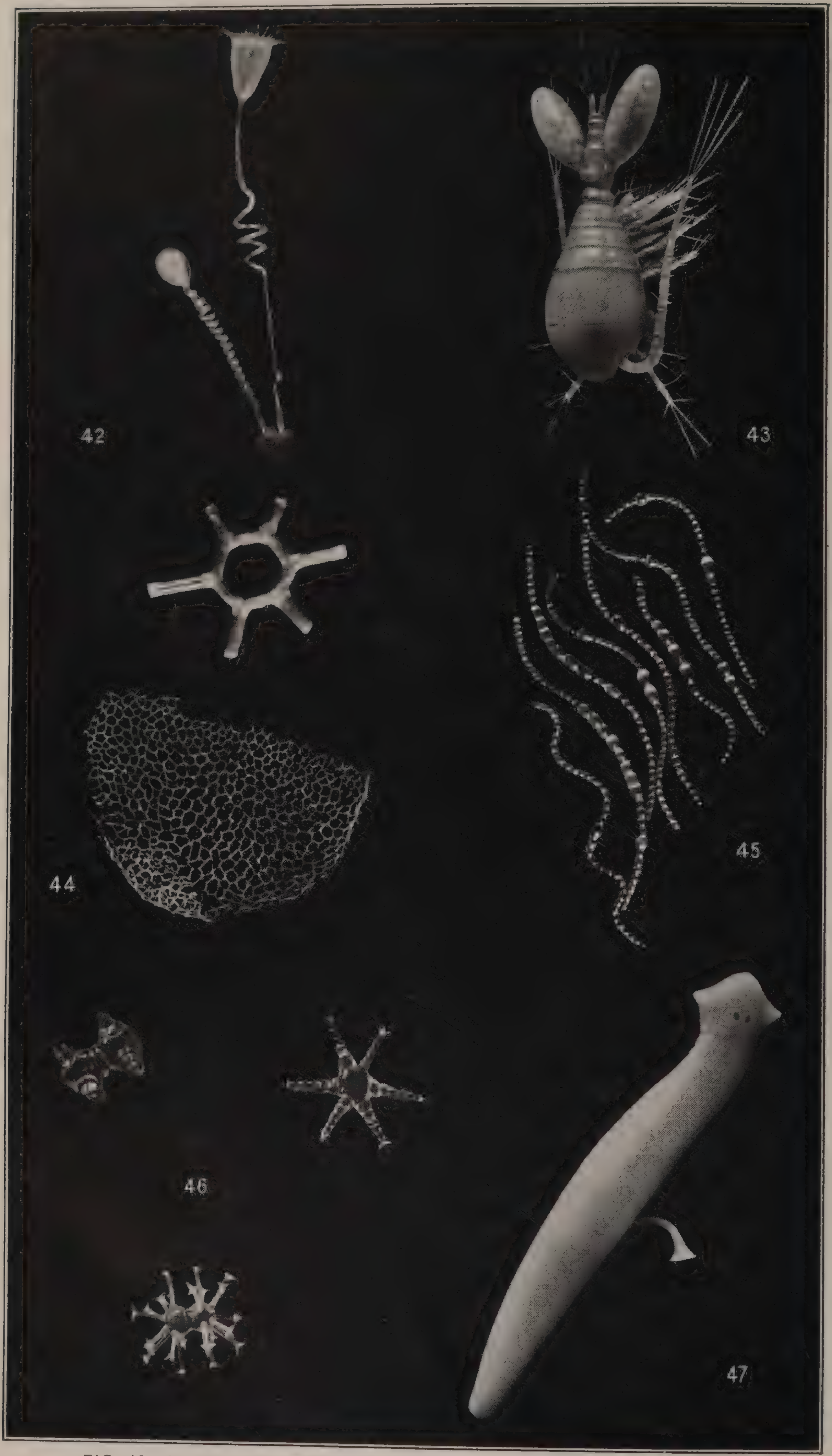

FIG. 42.—VORTICELLA.
FIG. 44.—HYDRODICTYON.
FIG. 46.—STAURASTRUM.

FIG. 43.—CYCLOPS.
FIG. 45.—ANABOENA.
FIG. 47.—PLANARIAN.

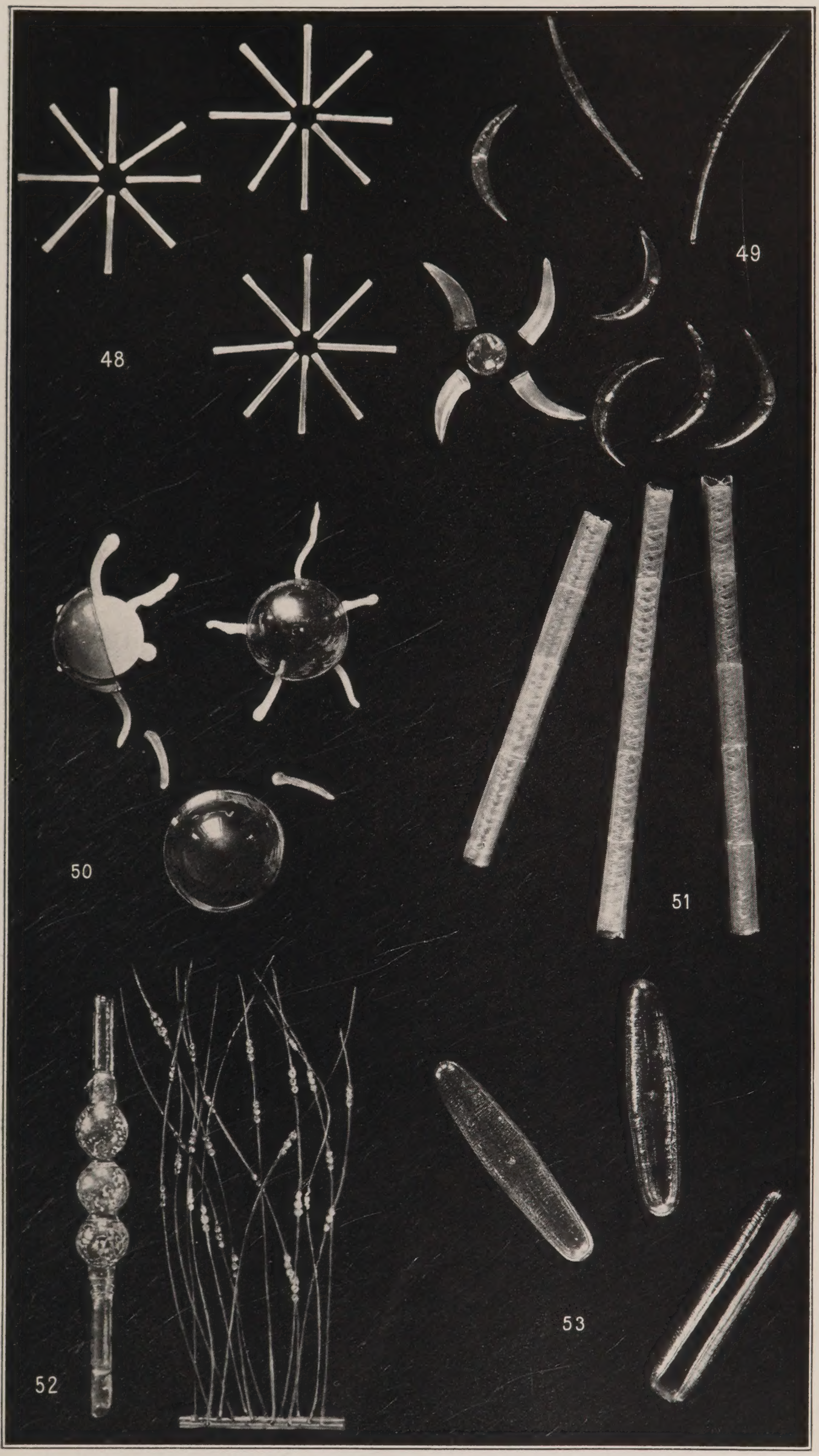

FIG. 48.—ASTERIONELLA.
FIG. 49.—CLOSTERIUM.
FIG. 50.—ARCELLA.
FIG. 51.—SPIROGYRA.
FIG. 52.—OEDOZONIUM.
FIG. 53.—NAVICULA.